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Exploring the similarities between informal and medieval settlements: A methodology and an application

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ABSTRACT

Most urban growth is taking place in the developing countries of the Global South through informal settlements. This form of development is usually strongly opposed by governments and local administrations. However, several works compared them to vernacular urban centres, such as medieval towns, and praised their human-scale qualities. If this similarity were to be systemically assessed on a larger scale, informal settlements would gain more recognition and legitimation. This, in turn, can potentially impact policy making. In this paper, we propose a replicable methodology based on the use of open data to investigate similarities between informal and medieval settlements, through statistical comparison of metrics of urban form and correlation analysis between densities of amenities and street centrality (a fundamental relationship at the basis of city functioning). This methodology is tested on three informal settlements in Sub-Saharan Africa and three Italian medieval towns. Statistical similarities were found, especially for what concerned aspects of the urban fabric, configurational features, and the relationship between densities of amenities and street centrality. These findings add to the studies that recognise the value of informal settlements. Furthermore, the proposed methodology can be replicated to increase the generalisability of this result and further legitimise informal urban development.

1. Introduction

The world is undergoing a process of fast and unprecedented urbanisation. Official reports estimate that 68% of the world total population will live in cities by 2060 (DESA UN, 2018). However, this process takes place unevenly across the globe with an estimated growth, for the period 2018–2030, of less than 1% in most cities of the developed countries and between 1% and 5% in the ones of the developing countries of the Global South (i.e., Africa, Latin America, and South Asia) (DESA UN, 2018). It is argued that this vast displacement of people towards urban centres is related to the increasing economic divide between the less advantaged rural areas and the more prosperous urban regions (Locatelli & Nugent, 2009), but also to the effects of climate change, such as the progressive desertification of rural lands (Barrios et al., 2006). The large majority of these displaced populations end up by building their own makeshift houses in informal settlements, i.e. residential areas where a group of housing units has been constructed on land to which the occupants have no legal claim, or which they occupy illegally (UN-HABITAT, 2003).

Due to their unregulated status, informal settlements have long been – and still are – opposed by the local administrations of several countries. In some extreme cases, this hostility even resulted in episodes of slum clearance, for example in Zimbabwe (The Economist, 2005) and Brazil (Phillips, 2011). Conversely, several researchers, especially in the fields of urban design and urban morphology, have a diametrically opposite perspective on this form of urban development, praising their irregularity and organic shapes, and comparing them to vernacular urban centres, such as medieval towns (Kellett & Napier, 1995; Lawrence, 1990; Rapoport, 1988; Stea & Turan, 1990). The latter are reported to possess several desirable design features, such as a human-scale/well-connected urban fabric, that not only fosters commerce and social interactions, but also favours pedestrian movement and the

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overall well-being of city residents (Gehl, 2011; Jacobs, 1961; Lynch, 1995).

Thus if the similarity between recently built informal settlements and medieval urban centres were to be demonstrated in more depth and at a larger scale, the existence and development of the former would be more robustly legitimised, eventually leading to the formulation of policies aimed at their preservation and upgrading. Several researchers studied informal settlements, in different parts of the world, through replicable techniques and provided more generalisable findings. However, the hypothesis of similarity between these settlements and medieval towns has never been verified.

Recently, two works more closely focused on this topic by means of quantitative comparative analyses. Porta et al. (2014) focused on the street networks of more than 100 settlements around the world and reported that the average length of main street segments in medieval and informal settlements was close to 400 m. Although these results are more generalisable and identify an important similarity, they only concern one single morphological aspect (i.e., street length). Urban form, though, is a much more complex entity (Jacobs, 1961), which not only includes aspects of the street network, but also shapes and relations between buildings and presence and spatial distribution of functions, such as commerce and services. A more thorough analysis was conducted by Iovene (2018), who carried out a diachronic comparative analysis between an informal settlement in Peru and a neighbourhood in Venice (Italy). Although interesting similarities were found, especially concerning the growth of the two settlements, her work is hardly replicable as it requires historic data and spatial information at a very fine level of spatial granularity, both hardly retrievable for informal settlements. Finally, similarities were assessed without statistical testing.

In this paper, to more robustly legitimise informal settlements and address previous methodological shortcomings, we propose a replicable methodology that investigates and compares similarities between informal and medieval settlements, through a set of 12 metrics of urban form, measuring aspects of the urban fabric, configuration of the main street network (main streets and lanes), and presence of urban amenities (i.e., commerce and services), that can be easily computed and extracted from open data. More specifically, the proposed methodology consists of: (i.) assessing whether similarities are present between informal and medieval settlements, through the statistical comparison of the 12 metrics; (ii.) verifying whether a relationship exists between the density of amenities (i.e., commerce and services) and measures of street network centrality, a fundamental relationship at the basis of city functioning (Porta et al., 2012) and urban consolidation (Hillier et al., 2000). The first step is carried out through the implementation of a robust technique of statistical comparison (i.e., two-sample Kolmogorov-Smirnov test), that assesses the similarity between distribution functions. The second step of the methodology is carried out by correlating a street-based density measure of commerce and services and several street network centrality indices. While this methodology constitutes a valuable tool for comparing measurable aspects of urban form, we acknowledge that there exist further and possibly complementary ways to evaluate it, for example, through in loco qualitative observations and interviews, techniques which were at the basis of the works mentioned above (Gehl, 2011; Jacobs, 1961; Lynch, 1995).

The proposed methodology was tested on three informal settlements in Sub-Saharan Africa, namely Akweteman (Accra, Ghana), Kanyama (Lusaka, Zambia), Kibera (Nairobi, Kenya), and three Italian medieval towns, namely Perugia, Siena, and Viterbo. Results of the statistical comparison of the distributions revealed common patterns across basic properties of the urban fabric and aspects of the configuration of the main street network. Furthermore, statistically significant correlations were found between the density of commerce and services and the tested measures of street network centrality. In particular, betweenness centrality, computed for larger radii (i.e., 1600 m and global), was consistently associated with more density of amenities, across all case studies. The ensemble of these results suggests that the informal and medieval settlements under examination shared relevant similarities.

The findings of this analysis are aligned with previous theories (Kellett & Napier, 1995; Lawrence, 1990; Rapoport, 1988; Stea & Turan, 1990) and also add further evidence to the body of empirical studies that found similarities between informal settlements and medieval urban centres (Iovene, 2018; Porta et al., 2014). More importantly, though, the methodology proposed in this paper paves the way for more comparative analyses of this kind, which can further legitimise the existence of informal settlements and impact the formulation of policies aimed at their conservation and upgrading. However, further research should ascertain whether the observed similarities are unique to these contexts or are shared with other settings as well (e.g., pre-industrial, modern, contemporary).

The remainder of this paper is structured as follows. Firstly, we present studies related to the research presented in this paper. Secondly, we illustrate the methodology to compare features of urban form of the different settlements under examination and perform correlation analysis between densities of amenities and centrality measures. Thirdly, we present the outcomes of the application of the proposed methodology to the six case studies mentioned above. Finally, we conclude with limitations, future work, and final remarks.

2. Related works

Due to their irregular urban form and growth processes based on piecemeal addition (Montejano-Castillo, 2014), informal settlements have been often compared to vernacular urban forms by several scholars. Lawrence (1990) and Rapoport (1988), for example, although using different theoretical frameworks, both clearly qualified informal settlements as vernacular artefacts as their design and construction were inspired by traditional know-how rather than academic theories. Stea and Turan (1990) moved the argument at a societal level, suggesting the existence of two different place-making societies: the typically vernacular one, where people truly participate in the construction process, thus creating today's informal settlements and, for example, medieval towns, and a typically professional one, more market-driven, that generates the top-down modern extensions of the Western world. More recently, Kellett and Napier (1995) investigated informal settlements in Colombia and South Africa through a multidimensional framework that not only accounted for building type, use, and household characteristics, but also time progression. Although this framework was not aimed at the comparison of informal and vernacular settlements, it helped the researchers to identify commonalties among the two (e.g., the use of traditional building skills, design aspects reflecting a bottom-up approach). These works clearly provided a strong theoretical basis for the comparison between informal and medieval settlements, however, they are hardly generalisable as, although frameworks were proposed, no quantifiable metrics were defined and outcomes were still largely qualitative.

More recently, with the diffusion of GIS and better satellite imagery, several researchers investigated the forms of informal settlements through quantitative techniques. Barros Filho and Sobreira (2007), for example, investigated the forms of several planned and informal urban fragments in Recife (Brazil) through the analysis of satellite images. More specifically, they measured the settlements under examination by means of a metric of lacunarity (i.e., presence of empty spaces in the urban fabric), which the authors claimed to be a proxy for permeability, and found that informal settlements tended to show smaller values compared to planned neighbourhoods. Montejano-Castillo (2014) analysed Ciudad Nezahualcoyotl, an informal settlement in Mexico City, through several metrics concerning topographical conditions, block consolidation, size and shape of plots, and settlement age. The researcher found that topography impacted density and construction of the settlement; plot size largely influenced the internal development of the housing units; finally, the age of the settlement – and of its population – had a strong effect on land use (i.e., younger settlements were more commercially vibrant, while older ones tended to be more residential). Brelsford et al. (2018), investigated the lack of accessibility and services in informal settlements, through a topological analysis of neighbourhood maps, and proposed an algorithm of street network optimisation to provide better accessibility to services to the most segregated spaces of informal settlements. This algorithm was tested in Epworth, Harare (Zimbabwe), and Khayelitsha, Cape Town (South Africa), and provided alternative scenarios that granted better accessibility to services. Hillier et al. (2000) investigated the relationship between levels of street network accessibility (i.e., global and local integration), urban consolidation (measured as improvements to buildings and social ties over time), presence of commercial activities, crime levels, and household income, in 17 informal settlement of the Chilean capital. Findings of this research showed that higher levels of local integration were associated not only with better urban consolidation, but also with more commercial activities. This combination, in turn, was found to be related to lower crime levels. Although these works set important quantitative precedents for the analysis of informal settlements, they did not address the comparison with medieval ones.

To the best of the author's knowledge, only two works addressed this point. The first analysed one hundred main street networks of urban areas around the world, corresponding to urban design paradigms ranging from antiquity to present day, including informal settlements (Porta et al., 2014). Results showed that the average length of main street segments in historic settlements, including medieval, and informal case studies was close to 400 m, while the same measure in post-industrial urban extensions was much higher, between 800 and 1000 m. This study clearly pioneered quantitative comparative analyses between informal and medieval settlements. However, urban form is a much more complex entity (Jacobs, 1961), which can hardly be described through a single aspect (i.e., street length of main street segments). More recently, Iovene (2018) overcame this limitation by performing a diachronic comparative study between an informal settlement in Lima (i.e., San Pedro de Ate) and a medieval neighbourhood of Venice (i.e., Bartolomio) through multiple metrics of the built environment, such as, plot size, thoroughfares width, and mixed-use at block level. Outcomes showed that both settlements were characterised by a compact/small-scale urban fabric, high density, and street fronts fully built up. Moreover, the authors suggested that they both seemed to have undergone a similar growth process (i.e., fast at the beginning and slow at later stages). This study offers a more comprehensive perspective on similarities between an informal settlement and a medieval neighbourhood. However, outcomes are hardly generalisable as they are valid only for the two case studies considered. Furthermore, since some metrics requires data at a very fine level of spatial granularity, which is generally hard to obtain for informal settlements, the methodology is hardly replicable to further case studies. Finally, similarities were only assessed through visual inspections of graphs, thus lacking of statistical robustness. In this paper, we present a quantitative methodology for the comparison of informal and medieval settlements that is based on a set of metrics of urban form, that can be easily extracted from open data, robust statistical comparison and correlation analysis.

3. Methodology

The methodology proposed in this paper mainly consists of four parts: (i.) selection of case studies; (ii.) extraction of metrics of urban form from open data; (iii.) application of the two-sample Kolmogorov-Smirnov test to ascertain whether the distributions of these metrics are similar across the case studies; (iv.) correlation analysis to understand whether the spatial distribution of urban amenities is associated with measures of street network centrality. Before presenting each step in detail, we introduce the dataset from which to extract the proposed metrics of urban form.

3.1. OpenStreetMap

OpenStreetMap (OSM) is probably the best known online project of geographic crowd-sourcing. As of September 2019, its total number of contributors stands at 5.6 million. The aim of this project is to build the first, freely accessible, map of the entire world. To do so, OSM contributors map a wide variety of geographical objects, such us, roads, buildings, and natural features, through different online and offline tools. In OSM, there exist three main types of spatial entities: *ways*, which represent streets, *nodes*, which are Points Of Interests (POIs), such as, restaurants, schools, or places of worship, and *relations*, which represent areal elements, such as, buildings and parks. The spatial accuracy of such information is particularly high in urban areas of developed countries (Girres & Touya, 2010; Haklay, 2010; Ludwig et al., 2011). However, this has to be demonstrated yet in developing countries, and, although mapping initiatives for humanitarian purposes (e.g., Missing Maps)[3] have recently started to target these countries (including informal settlements), maps might still be incomplete and present uneven coverage. In the next paragraph, we thus propose a technique to contravene this issue. To compute the metrics of urban form proposed in this paper, the following OSM objects should be considered: streets, POIs, and buildings.

3.2. Selection of case studies

To carry out the comparative analysis between medieval and informal settlements, we present next four criteria to guide the selection of the case studies:

1. *Morphology*. Medieval towns are urban centres densely built that feature organic layouts due to a spontaneous urban growth. They were founded before or after the Romans and did not undergo extensive re-configurations throughout history. Their consolidation and development mainly took place between the V and the XV century. Since medieval towns developed in a dense manner without major pre-existing urban constraints, the informal settlements to be selected should respect this condition as much as possible. Their modes of growth should be aligned with the *settling* (i.e., their development took place on "unclaimed and often unbounded land") and *inserting* (i.e., their growth happened into the "uninhabited, abandoned or leftover fragments of urban space") processes proposed by Dovey and King (2011). Furthermore, drawing from the same study, the typology *district*, denoting informal settlements that developed over time to become "large mixed-use districts", which "cannot be described anymore as infiltrations or encroachments", should be preferred for carrying out the analysis.
2. *Presence and validity of OSM data*. To implement the methodology proposed in this paper, the OSM spatial objects presented in the paragraph above should be present in the selected case studies and should be reliable. Since it would be extremely expensive and time-consuming to double-check recorded OSM information on the field for multiple case studies, we propose a technique to improve accuracy based on visual comparison between OSM data and satellite pictures, which are nowadays easily retrievable in GIS or even through more popular software (e.g., Google Earth). The aim of this comparison is to find discrepancies between the two sources of spatial data and, in particular, to identify and integrate missing buildings and streets. The former can be added by drawing roof edges from the satellite imagery used for comparison. To detect the latter, neat and continuous cuts in the urban fabric should be considered as potential signs of street presence. If the OSM data does not cover these cuts, new street segments should be added to reflect the real situation in the settlement. Examples of these additions can be found

[3] https://www.missingmaps.org/.

in the section Application and, more specifically, in Figs. 1 and 2. We argue that the implementation of this technique can grant enough data coverage for the scale at which the proposed metrics of urban form are computed.

3. *Topography*. The topography of the site influences the form of settlements (Montejano-Castillo, 2014). For example, informal settlements built on steep flanks tend to grow in very constrained spaces and thus tend to be particularly dense and characterised by curved roads, that follow the topographic lines of the site. Conversely, settlements built on flat regions tend to occupy more land and thus densities are lower and streets are straighter. It is thus important that the case studies, both informal and medieval settlements, present similar topographic conditions.
4. *Size*. The size of the case studies should be similar as an unbalanced selection could undermine the robustness of the statistical analysis. We thus suggest basing the selection of the case studies on similar values of settlement area and numbers of street segments.

3.3. Measuring urban form

Given the crowd-sourced nature of the suggested data source and its likely uneven level of detail, we propose a set of metrics of urban form that is comprehensive but that, at the same time, adapts to such circumstances and thus quantifies aspects at the street and block levels rather than at a finer level of spatial granularity. More specifically, our methodology requires the computation of 12 metrics: four measure aspects of the urban fabric, one quantifies the density of commerce and services at street level, while seven measure the configuration of the main street network. Note that, to avoid edge effects when computing the latter, the main street networks selected for the analysis ought to be larger than the boundaries of the case studies considered. While there is no established rule for avoiding this issue, we provide the following example for guidance. If a settlement measures 1 km radius, all street segments within 3 km radius from its centroid should be considered. In the next subsections, we present the 12 metrics of urban form and how to compute them.

3.3.1. Metrics of the urban fabric

These metrics account for basic morphological features of the settlements and are:

- Block size (BS). It is the area, in square meters, delimited by road centre lines;
- Coverage ratio (CR). It represents the percentage of land that is occupied by buildings in each block;
- Street length (SL). It is the length, in meters, of each street segment (i.e., the line connecting two intersections).

3.3.2. Density of amenities at the street level

The Network Kernel Density of amenities (NKA) measures the density of commerce and services at the street level. It is computed through the technique developed by Okabe and Sugihara (2012), which, in brief, works as follows: firstly, each amenity, which is represented by a georeferenced point, is assigned to the closest street segment; secondly, a gaussian interpolation is applied to the count of these amenities and a street-based density value is output for each street segment.

3.3.3. Metrics of the configuration of the main street network

To measure aspects of the configuration of the main street network of the settlements under examination, our methodology relies on Node degree (ND) and two well-established metrics of network centrality, i.e. betweenness and closeness. The former is a measure of connectivity and represents the number of streets connected to each intersection. Betweenness centrality measures the level of through-movement in the main street network under examination. To be more specific, it is based on the concept that a node (i.e., a street intersection) is central if it lies on many of the shortest paths linking couple of nodes in a street network (Porta et al., 2006). Our methodology requires the computation of betweenness centrality at four different scales, representing four different urban scales:

- 400 m (BET400). This is a micro-scale, corresponding to the sanctuary area, an urban sub-space usually comprising of few blocks surrounded by main roads, typical of the pedestrian-oriented urban fabric (Mehaffy et al., 2010);
- 800 m (BET800). This is a geographic scale widely adopted to define neighbourhoods (e.g., in New Urbanist schemes), which derives from the half-mile Jeffersonian grid;
- 1600 m (BET1600). This is a meso-scale which represents city districts (i.e., ensembles of two or more neighbourhoods);

Fig. 1. Increasing data coverage in Akweteman. In green, the original OSM street network. In red, the added streets. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

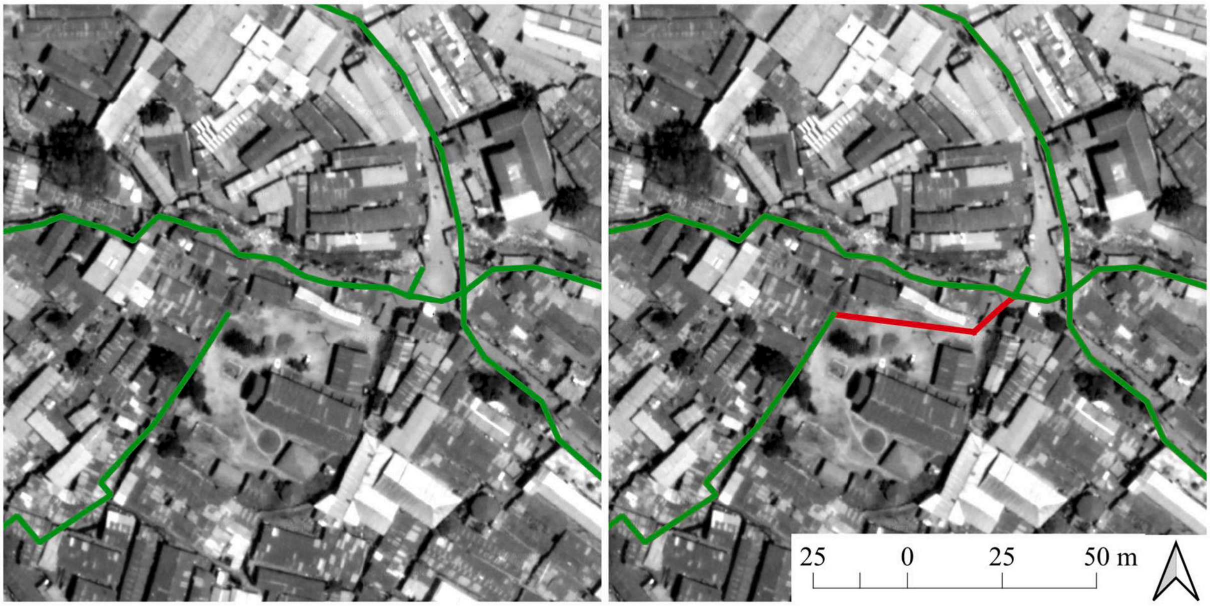

Fig. 2. Increasing data coverage in Kibera. In green, the original OSM street network. In red, the added street. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

- Global (BETGLO). This represents a macro-scale and corresponds to the entirety of the main street network under examination.

Closeness centrality quantifies instead the level of proximity and interconnectedness of street segments, in a street network. More specifically, *Closeness centrality* measures to what extent a node is near to all the other nodes in a network along the shortest paths (Porta et al., 2006). Our methodology requires the computation of this measure for all the scales proposed for betweenness centrality, except the global one. This scale usually does not provide useful information since greater values are uniformly located at the centre of the street network under examination. Closeness centrality should thus be computed at the following scales:

- 400 m (CLO400);
- 800 m (CLO800);
- 1600 m (CLO1600).

3.5. *Assessing similarities across informal and medieval settlements*

Having computed the metrics of urban form presented above for both informal and medieval settlements, the two-sample Kolmogorov-Smirnov test (usually abbreviated to KS test) should be implemented to assess similarities across them. The KS test is a statistically robust technique that assesses the similarity between the probability distribution functions of two variables through a non-parametric null hypothesis test (Conover, 1971). More specifically, the KS test quantifies the distance between the empirical distributions of two samples, under the null hypothesis that the samples are drawn from the same distribution. In practice, when this happens the KS statistic (i.e., D) is usually close to 0, meaning that the distance between the two distributions is small, and the p-value is greater than a significance threshold, usually set at 0.05. The two-sample KS test is one of the most widely adopted statistical techniques for comparing the distributions of two variables as it is sensitive to differences in both location and shape of the distribution functions (Conover, 1971). Since the KS test only provides information on the presence or absence of statistical similarities but not on the actual values of the tested metrics, box plots (i.e., a graphical method for representing data through quartiles) should be used to investigate the observed similarities in a quantifiable manner. The combination of KS test and box plots thus provides information both on the presence of statistically robust similarities across metrics and on the ranges of values for which these similarities are valid.

3.6. *Assessing the relationship between density of amenities and street centrality*

Previous works showed that the metrics proposed in this paper tend to be skewed. For example, researchers observed this phenomenon in the distributions of betweenness centrality (Barthelemy, 2004; Jiang, 2009) and street length (Jiang, 2009). For this reason, our method requires the Spearman correlation (Corder & Foreman, 2014) to evaluate the relationships between the centrality measures and the density of amenities at the street level as it is robust against skewed distributions. It assesses, in fact, a monotonic relationship based on ranks rather than continuous values. The output of this correlation is a coefficient (r_s), that varies between −1 (i.e., perfect negative relationship) and 1 (i.e., perfect positive relationship), and a p-value that provides information on the statistical significance of the test. Having provided all the methodological steps needed to carry out the comparative analysis proposed in this paper, we present next their application to a set of selected case studies.

4. Application

4.1. *Case studies*

The analysis carried out in this study focuses on the comparison between the forms of three informal settlements located in Sub-Saharan Africa, namely, Akweteman (Accra, Ghana), Kanyama (Lusaka, Zambia), Kibera (Nairobi, Kenya), and three medieval Italian towns, namely, Perugia, Siena, and Viterbo. These settlements were chosen as OSM data (i.e., buildings, streets, and amenities) was available, the authors were familiar with them, see, for example, Mottelson and Venerandi (2020), and they were compliant with the four selection criteria illustrated in the Methodology. To be more specific, all settlements are the result of mainly self-organised processes which did not follow planning directives. The three Italian case studies are paradigmatic examples of medieval towns of central Italy (located in Umbria, Tuscany, and Lazio, respectively), lacking the imprinting of a regular Roman foundation. Indeed, Perugia was founded by the Umbrians (*"Perugia,"* 2018), a pre-Etruscan population, while Siena and Viterbo have Etruscan origin ("*Siena*," 2020; "*Viterbo*," 2013). Furthermore, the current forms of their centres are mainly the product of the urban development carried out in the XII-XIV centuries, which mainly consisted of small interventions in the urban fabric (e.g., rectification of a street, creation of a new square). These changes hardly affected the overall urban structure and thus have a very limited impact on the metrics of urban form proposed in this paper. The rectification of a street, for example, does not alter the topology of the street network as the number of streets connected to intersections stays the same, thus the values of the configurational metrics do not change. Akweteman, Kanyama, and Kibera were selected because they developed in a dense manner in areas relatively devoid of strong spatial constraints (e.g., rivers, rail tracks, highways). Their growths seemed to have taken place through the *settling* and *inserting* modes proposed by Dovey and King (2011) and align with the *district* typology as they are mixed-use and relatively large in size. In terms of presence and validity of OSM data, the six settlements presented different levels of data coverage. By inspecting satellite pictures and data extracted from OSM, we observed that buildings were mapped at a sufficient level of detail across all the settlements under examination. However, this was not the case for main street networks. In fact, while the three medieval Italian towns and Kanyama showed accurate spatial information, Akweteman and Kibera did not. We thus used the technique presented in the section above to increase data coverage in these two settlements. We present in Figs. 1 and 2 examples of additions to the main street networks of Akweteman and Kibera, respectively.

In terms of site topography, the six settlements were comparable and characterised by the absence of steep topographic conditions. Finally, the selected settlements were similar in size, with total areas going from 127 ha (Kibera) to 334 ha (Kanyama) and total number of main street segments ranging between 309 (Kibera) and 837 (Kanyama). OSM data for carrying out this analysis was obtained in March 2019. In Fig. 3, we present a map for each of the settlements under examination, while, in Table 1, we provide areas and number of OSM features.

4.2. Statistical comparison of informal and medieval settlements

Having selected the case studies, improved accuracy of spatial information, and computed the metrics of urban form, we implemented the two-sample KS test to compare the distributions of these metrics, across all possible pairwise combinations of settlements, and search for statistical similarities. Next, we present the outcomes for each metric and whether similarities held for both informal and medieval settlements (green squares in Fig. 4), only for the former (light blue squares in Fig. 4), only for the latter (yellow squares in Fig. 4), or for none of them (blank square in Fig. 4). Furthermore, to connect these findings to measurable units, we present box plots for each metric and settlement in Fig. 5. We anticipate that no similarity was found, for any combination of settlements, for CLO800, CLO1600, and NKA. These will thus not be mentioned in what follows.

Distributions of BS were found statistically similar in a combination of informal settlements (i.e., Kanyama – Kibera) and in three couples of medieval towns (i.e., Perugia – Siena, Perugia – Viterbo, and Siena – Viterbo). In the former, the D statistic was 0.08, meaning that differences between the tested distributions were very small,[4] and median values were 10,328 m^2 (Kanyama) and 11,158 m^2 (Kibera). In the latter, D statistics ranged between 0.06 and 0.13 and medians between 3969 m^2 (Perugia) and 4534 m^2 (Siena).

CR was found statistically similar in two combinations of informal and medieval settlements (i.e., Kibera – Siena and Kibera – Viterbo), with D statistics equalling 0.15 and 0.18, respectively. Medians ranged between 53% (Siena) and 58% (Kibera).

Distributions of ND were found similar across all combinations (i.e., 15) of informal and medieval settlements. The KS tests consistently showed small values of the D statistic (i.e., between 0.01 and 0.08), with medians tending to three in both informal and medieval settlements, pointing to the fact that most intersections had three streets converging at them.

SL was found similar in three combinations of informal and medieval settlements (i.e., Akweteman – Perugia, Akweteman – Siena, and Akweteman – Viterbo), in a couple of informal settlements (i.e., Kanyama – Kibera), and in three couples of medieval towns (i.e., Perugia – Siena, Perugia – Viterbo, and Siena – Viterbo). In the first, D statistics were found valid and ranged between 0.04 and 0.08. Furthermore, median values went from 46.5 m (Akweteman) to 52.4 m (Perugia). In the second, the D statistic was 0.07, while medians were 72 m and 74 m. In the third, D statistics ranged between 0.05 and 0.06, while medians between 48 m (Siena) and 52 m (Perugia and Viterbo).

BET400 was found statistically similar in three combinations of medieval towns (i.e., Perugia – Siena, Perugia – Viterbo, and Siena – Viterbo). D statistics went from 0.05 to 0.07, while medians ranged between 4.465 (Siena) and 4.929 (Viterbo).

Distributions of CLO400 were similar in two couples of informal and medieval settlements (i.e., Kibera – Perugia and Kibera – Viterbo) and in one combination of medieval towns (i.e., Perugia – Viterbo). In the former, D statistics were 0.08 in both cases, while medians went from 0.003818 (Kibera) to 0.003879 (Perugia). In the latter, the D statistic was 0.06 and the medians were 0.003879 (Perugia) and 0.003844 (Viterbo).

BET800 was found similar only in three couples of medieval towns (i.e., Perugia – Siena, Perugia – Viterbo, and Siena – Viterbo). D statistics varied between 0.04 and 0.06 and median values between 7.916 (Siena) and 9.067 (Perugia).

BET1600 was found similar in a combination of informal settlements (i.e., Akweteman – Kibera) and in two couples of medieval towns (i.e., Perugia – Siena and Siena – Viterbo). In the first, the D statistic was 0.06 and medians went from 9.196 (Akweteman) and 9.433 (Kibera). In the second, D statistics were 0.05 and 0.06, respectively, while medians ranged between 11.741 (Viterbo) and 16.338 (Perugia).

Finally, distributions of BETGLO were found statically similar in three combinations of informal and medieval settlements (i.e., Kibera – Perugia, Kibera – Siena, and Kibera – Viterbo) and in one couple of medieval towns (i.e., Perugia – Siena). In the former, D statistics varied between 0.05 and 0.08 and medians between 11.903 (Viterbo) and 22.446 (Perugia). In the latter, the D statistic was 0.04, while medians were 22.446 (Perugia) and 20.064 (Siena).

The outcomes of the KS tests showed the presence of strong similarities between the informal and medieval settlements under examination, in terms of ND, i.e. most intersections had three streets converging at them, a feature associated with bottom-up processes of city building based on the mobility needs of the pedestrians (Hamouche, 2009; Ribeiro, 1997). Further similarities, although less consistent across cases, were found for SL, with medians ranging between 46.5 m (Akweteman) and 52.4 m (Perugia), which are again typical of fine grained/highly walkable urban environments; CR, with medians between 53% (Siena) and 58% (Kibera), corresponding to relatively dense urban fabrics; CLO400, with medians between 0.003818 (Kibera) and 0.003879 (Perugia), and BETGLO, with medians between 11.903 (Viterbo) and 22.446 (Perugia), suggesting that both informal and medieval settlements have similar levels of street interconnectedness at the very local scale and through-movement at the largest scale of analysis. This supports the qualitative theories that compared informal settlements to vernacular urban forms (Kellett & Napier, 1995; Lawrence, 1990; Rapoport, 1988; Stea & Turan, 1990) and adds to the body of quantitative works that found measurable similarities across medieval and recently built informal settlements (Iovene, 2018; Porta et al., 2014), thus strengthening the legitimation of the latter as urban

[4] For comparison's sake, consider that, in terms of BS, the greatest D statistic, representing the greatest difference between distributions, was 0.48 and was found in the couple Akweteman–Kibera.

Fig. 3. The six settlements under examination.

Table 1
Areas of settlements and number of OSM features in each case study.

Settl. type	Settl. name	Area (ha)	No. POIs	No. main streets	No. buildings
Informal	Akweteman	160.04	388	506	6364
	Kanyama	333.60	176	837	10,985
	Kibera	127.18	418	309	8056
Medieval	Perugia	177.74	215	726	1540
	Siena	223.61	172	651	411
	Viterbo	173.79	52	616	377

fragments worthy of protection and upgrading rather than demolition. The similarities found only between combinations of informal settlements or medieval towns, for example in terms of BS and SL, could be associated with different stages of urban development: the "in the making" condition of informal settlements, which were only recently established and feature larger blocks and longer streets; and the consolidated status of long-established medieval towns, characterised by smaller blocks and shorter streets. We thus hypothesise that, if the current growth of informal settlements is not stopped or altered, they might eventually reach in time the level of consolidation of medieval towns. The analytical comparison presented in this paper does not control for city areas that developed in non-spontaneous manners, meaning that the observed similarities might apply to other types of urban developments as well. However, the results presented by Porta et al. (2014) point to the fact that informal settlements and medieval towns are similar to each other and, at the same time, different from city areas designed by following post-industrial planning concepts. This, to a certain extent, supports the results presented in this paper.

4.3. *Testing the relationship between density of amenities and street centrality*

The second part of our methodology required to ascertain whether both informal and medieval settlements obeyed a fundamental rule at the basis of city functioning, i.e. the location of amenities on streets with higher levels of network centrality. To ascertain such point, we applied the Spearman correlation to test the relationship between NKA and the seven centrality measures considered, in each of the settlements under examination. Outcomes (Table 2) showed that most correlations (i.e., 88% of them) were statistically significant (p-value $\leq$ 0.05), with r_s values varying between 0.08 and 0.58. The measures of betweenness centrality for radii above 400 m were more consistently associated with NKA than the other centrality measures, across informal and medieval settlements. In particular, BETGLO and BET1600 showed the strongest and most consistent relationships, with r_s values varying between 0.09 (in Kanyama) to 0.29 (in Kibera), and between 0.11 (in Kanyama) to 0.30 (in Siena), respectively. This meant that streets with more through-movement at the district scale tended to host more amenities in both informal and medieval settlements. While this pattern is in line with previous research focusing on historic Western cities, for example Bologna (Porta et al., 2009) and Barcelona (Porta et al., 2012), it is shown to hold true, for the first time, in recently built informal settlements as well. For what concerns the relationships between measures of closeness centrality and NKA, these were more varied, instead. More specifically, at the small scale (i.e., 400 m), closeness centrality tended

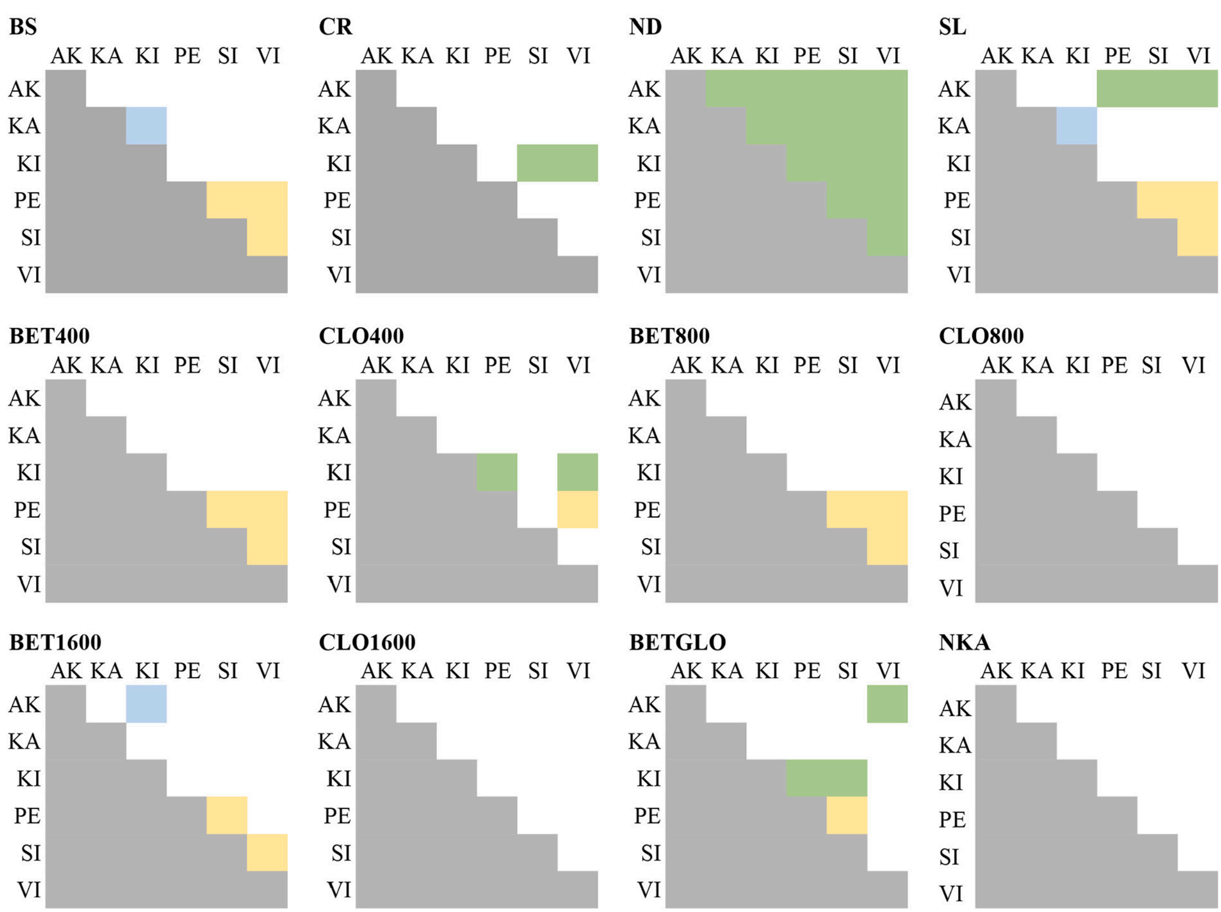

Fig. 4. Outputs of the two-sample KS test for each metric, across all possible pairwise combinations of settlements. AK: Akweteman; KA: Kanyama; KI: Kibera; PE: Perugia; SI: Siena; VI: Viterbo. In green: similarities across informal and medieval settlements. In light blue: similarities only across informal settlements. In yellow: similarities only across medieval towns. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

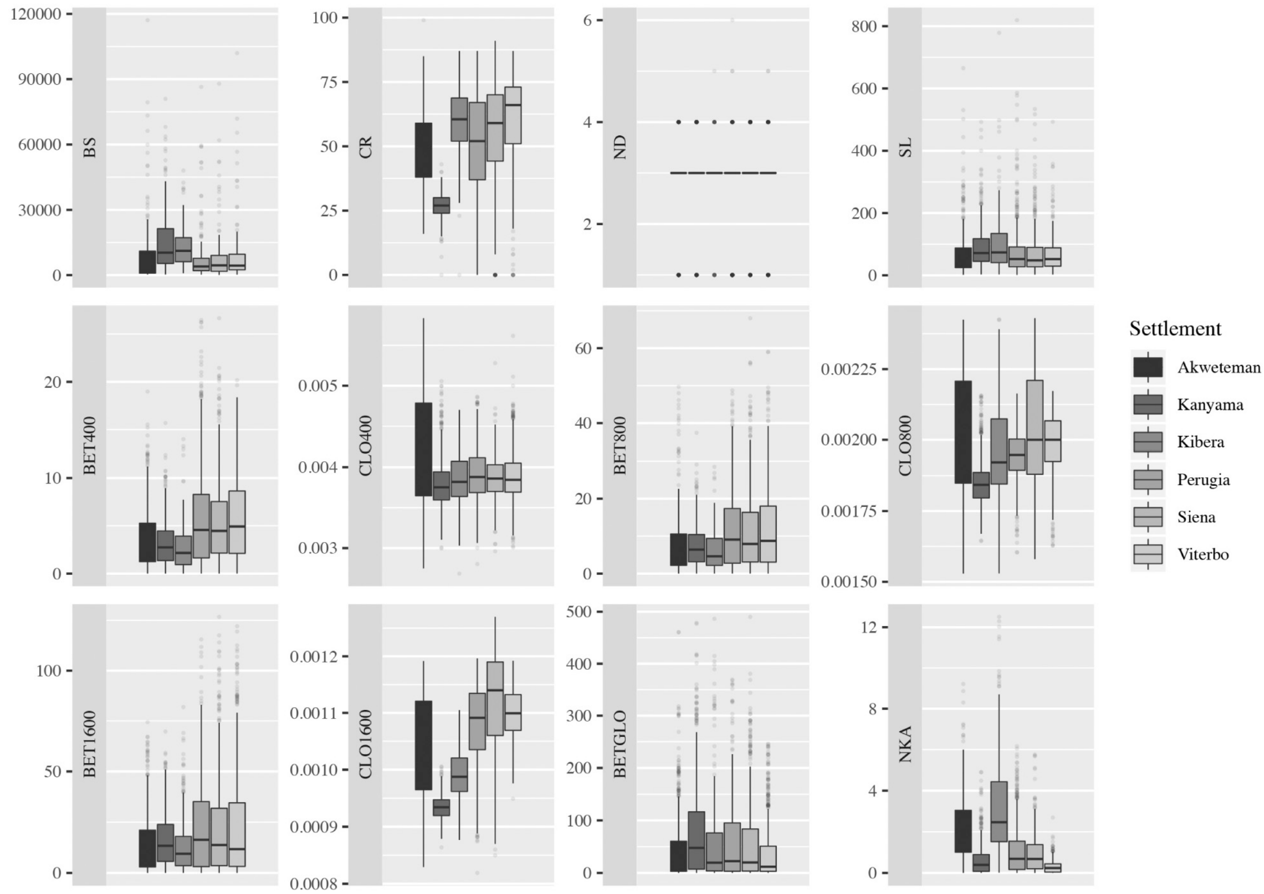

Fig. 5. Box plot for each metric and settlement under examination.

Table 2
Spearman correlation analysis between the NetKDE of amenities (NKA) and centrality measures, for the settlements under examination. Darker red corresponds to stronger inverse relationship. Darker green represents stronger positive relationship. Light blue means the correlation is statistically significant (p-value ≤ 0.05).

Metrics	Akweteman		Kanyama		Kibera		Perugia		Siena		Viterbo	
	r_s	p-v.	r_s	p-v.	r_s	p-v.	r_s	p-v.	r_s	p-v.	r_s	p-v.
BET400	−0.09	0.04	0.03	0.35	0.10	0.08	0.27	0.00	0.27	0.00	0.19	0.00
CLO400	−0.39	0.00	0.04	0.21	−0.26	0.00	0.19	0.00	−0.01	0.73	−0.08	0.04
BET800	0.10	0.02	0.08	0.03	0.24	0.00	0.27	0.00	0.30	0.00	0.21	0.00
CLO800	−0.23	0.00	−0.15	0.00	−0.19	0.00	0.49	0.00	0.35	0.00	0.02	0.62
BET1600	0.21	0.00	0.11	0.00	0.29	0.00	0.24	0.00	0.30	0.00	0.24	0.00
CLO1600	−0.18	0.00	−0.11	0.00	0.22	0.00	0.57	0.00	0.39	0.00	0.45	0.00
BETGLO	0.22	0.00	0.09	0.01	0.29	0.00	0.20	0.00	0.26	0.00	0.23	0.00

to be negatively associated with density of amenities, except in Perugia, pointing to the fact that strong local street interconnectedness did not seem to be beneficial for the presence of amenities. At 800 and 1600 m, the relationship between closeness centrality and density of amenities, when statistically significant, showed opposite signs in informal and medieval settlements, i.e. positive in the latter and negative in the former. We hypothesise that this might be due to the different geneses of the settlements under examination. While the former developed in mainly rural territories, growing as self-reliant chief towns within their respective regions, thus concentrating amenities in their cores, the latter developed in peri-urban areas and relied upon nearby existing neighbourhoods for access to commerce and services. The only exception was Kibera, that showed a positive relationship between closeness at 1600 m and density of amenities. We will return on this point in the section Future work.

5. Limitations

The methodology and results presented in this paper have several limitations. The first regards the conception of the former as it is centred on urban morphometrics, i.e. those aspects of urban form and street network configuration that can be quantified through the application of computer-aided algorithms. Although these are necessary to perform the comparative analysis presented in this paper, they are not able to fully account for the multi-faceted nature and complexity of the urban realm. For example, ethnographic and sociocultural aspects of the settlements, normally investigated through qualitative techniques (e.g., in loco observations, interviews), are not presently accounted for.

A second limitation concerns the absence of a baseline comparison with city areas that developed (or were built) differently from informal and medieval settlements. Thus the statistical similarities found across the two groups for CR, ND, SL, CLO400, and BETGLO might also concern other types of urban development. Although the study by Porta et al. (2014) shows a clear distinction between informal settlements and medieval towns, on one side, and post-industrial urban extensions, on the other, this is a point that needs to be investigated further.

A further limitation regards the source of spatial information (i.e., OSM). As we explained above, although previous studies found OSM data to be accurate and various humanitarian initiatives mapped several informal settlements around the globe, it is still likely that inaccuracies are present or that crucial spatial information is missing completely. To avoid this, we proposed a technique, based on the inspection of satellite imagery, to manually add missing streets and buildings. We acknowledge, though, that this might not be sufficient and that some streets might still be missing. To a certain extent, this absence can bias the values of the metrics proposed in this paper. For example, the distribution function of SL might be biased towards greater values, if smaller streets were to be absent from the dataset. OSM POIs, representing commerce and services, are further elements that might be missing or placed inaccurately. However, the one metric based on this data (i.e., NKA) is computed through a smoothing technique that outputs a density measure at the street level, thus an eventual partial absence of POIs might not constitute a severe bias. Due to the use of open data and satellite imagery for improving coverage, the methodology presented in this paper focuses, among other aspects of urban form, on the configuration of the main street network, which includes main streets and lanes. However, we acknowledge that informal and medieval settlements also feature smaller public laneways, such as tunnelled or cantilevered passageways, which are hardly detectable through the method for increasing data coverage presented in this paper. This, to a certain extent, can bias the outcomes presented in this paper.

The proposed scale of analysis is intermediate as it focuses on streets and blocks. Although this choice might help to bypass non-spontaneous interventions in the urban fabric, it does not permit to capture design subtleties associated with generative processes typical of different cultural contexts. Finally, although 88% of the tested correlations were statistically significant, the coefficients (i.e., r_s) showed weak to moderate values thus the inferences made on these results should be taken cautiously.

6. Future work

Although the study presented in this paper is a step forward in comparison with the state-of-the-art presented in the Related works section, results are hardly generalisable as they are limited to six settlements and two geographic contexts (i.e., Sub-Saharan Africa and Italy). Future work should thus focus on applying the proposed methodology to case studies in different geographic contexts, for example, by considering medieval towns in France, England, and Iran, and informal settlements in India, Brazil, and the Philippines.

The relationships between CLO800 and NKA and CLO1600 and NKA were found to be negative in most informal settlements and positive in the medieval towns. We thus hypothesised that, while the former grew in interstitial spaces left over by urbanisation and relied on the surrounding neighbourhoods for commerce and services, the latter grew as chief towns in rural territories and thus amenities flourished in their cores. However, Kibera was an exception as CLO1600 and NKA were positively correlated. We suggest that, since Kibera was established at the beginning of the 20th century (De Smedt, 2009), it might have developed, in time, a commercial fabric that well correlated with street interconnectedness at the district level, as in the medieval settlements under examination. This hypothesis seems to be in line with the study by Hillier et al. (2000), who found that urban consolidation was correlated with both higher levels of local integration (i.e., local closeness) and more economic activities at the street level. It might well be that the other informal settlements under examination might develop, in time, a similar relationship and thus reach the level of consolidation of the medieval towns. Indeed, ascertaining this aspect could be part of a larger research endeavour aimed at legitimising further informal settlements. This future work should involve the identification and analysis of other case studies, in both diatopic and diachronic manners, not only to strengthen the evidence on the similarity between informal and medieval settlements, but also shed more light on the consolidation process reported by Hillier et al. (2000) and Iovene (2018), and seemingly found in this analysis in Kibera.

Future research endeavours might also focus on the creation of a Python tool or package that automatically carries out comparison across settlements through the extraction of OSM data, computation of metrics at street and block levels, and statistical analysis. This can eventually improve an existing Python package, i.e. OSMnx (Boeing, 2017), that, at the moment, only computes metrics of the street network and outputs summary statistics at settlement level.

Finally, to investigate similarities (and differences) among informal and medieval settlements at a smaller scale, possible future work should focus on defining and testing metrics that quantify more subtle design aspects, for example, the presence or density of highly-symbolic public spaces or buildings. In so doing, our methodology might be able to investigate the impact that different socio-cultural contexts have on their relative urban forms. For this to happen, it is necessary that OSM reaches higher levels of coverage and accuracy (possible eventualities, given its constant growth in terms of users and mapped elements) or researchers integrate OSM data with information collected on the field.

7. Conclusions

The world is undergoing a process of fast and unprecedented urbanisation. Most of such growth is taking place in countries of the Global South, through the creation or accretion of informal settlements. These are often strongly opposed by governments and local administrations due to their unregulated status. However, several scholars value their physical qualities and compare them to vernacular urban centres, such as medieval towns. Few quantitative works reached similar conclusions. However, the urban form was only investigated through single metrics, such as in the work by Porta et al. (2014), or the methodology was hardly replicable, as in the work by Iovene (2018). If more generalised and in-depth proofs of the similarities between informal and medieval settlements were to be found, the former might gain more recognition and legitimation. This, in turn, might eventually impact the formulation of new policies aimed at their protection and upgrading. In this paper, we thus proposed a quantitative method for the comparison of informal and medieval settlements that is based on a set of metrics of urban form that can be easily extracted from OSM and robust statistical analysis. More specifically, similarities between the distributions of the metrics are assessed through box plots and KS test, a non-parametric null-hypothesis test that computes the distance between two distribution functions. Furthermore, the correlation between density of amenities and street network centrality, a fundamental relationship at the basis of city functioning, is assessed through the computation of the Spearman's coefficient. This methodology was applied to three informal settlements in Sub-Saharan Africa, namely, Akweteman, Kanyama, and Kibera, and three medieval towns, namely, Perugia, Siena, and Viterbo. Outcomes of such application showed the presence of several similarities across the case studies considered, for what concerned basic properties of the urban fabric (i.e., ND, SL, CR), two configurational aspects of the street network (i.e., BETGLO, CLO400), and the spatial distribution of amenities and street network centralities. More specifically, both informal and medieval settlements seemed to show a fine grained/organic urban fabric predominantly characterised by 3-way intersections, short streets (i.e., between 46.5 m and 52.4 m), moderately high coverage ratios (i.e., between 53% and 58%), thoroughfares well-connected with the surroundings, and well interconnected local streets. Furthermore, in both types of settlements, amenities were found to concentrate on main thoroughfares (i.e., streets with greater values of betweenness at larger radii). These findings enrich the body of literature that found similarities between informal and medieval settlements, further legitimising the former. Finally, the proposed methodology is replicable and can thus be applied to more case studies to improve the generalisability of these findings, which would eventually impact the debate on policy making targeting informal settlements.

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CRediT authorship contribution statement

Alessandro Venerandi: Conceptualization, Methodology, Software, Formal analysis, Visualization, Data Curation, Writing – Original draft, Writing - Review & editing; Maddalena Iovene: Resources, Validation, Writing - Review & editing; Giovanni Fusco: Methodology, Writing - Review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2021.103211.

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