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Diachronic investigation of the urban form of Qom (Iran) through morphometric approach

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Abstract

Qom is one of the oldest cities in Iran, with a multi-millennial history dating back to the 4th millennium BC, according to archaeological excavations. Due to different dominations (from ancient Persian dynasties to Islamic ones), the city has gone through successive phases of development and decay, which stratified in its urban form. More recently, due to its advantageous geographical position, several inter-city roads were constructed to converge in Qom, creating a radial structure, whose accessibility has been constantly improved by adding ring roads and filling gaps with local gridded networks. The sum of these transformations produced over time a complex urban form, which remains largely understudied. The aim of this paper is to investigate the morphology of Qom in a systematic manner through the use of a novel method of morphometric analysis based on multiple indicators of urban form describing aspects of the urban fabric and street network, as well as clustering techniques identifying homogeneous urban types in a hierarchical structure according to similarity. The application of this method to official datasets of plots and street segments, provided by the local administration, reveals 11 urban types with distinctive morphological traits, seemingly matching main phases of urban development. This morphometric analysis provides novel insights on one of the most ancient Iranian cities and can be replicated to investigate urban types in further case studies.

Keyword: *morphometrics, Qom (Iran), urban types, urban development*

Introduction

Qom is a historic city situated in the central part of Iran, at 125 km from the capital Tehran. It underwent different phases of development in its long history, resulting in a rich and stratified set of different urban fabrics. Saeidnia (1986) suggests that the ancient city core, built during the Sasanian dynasty and called Shahrestan, was located south-east of the current one, which was mainly developed in the Islamic era. The city of Qom experienced a slow growth rate until 1925, i.e., the end of the Qajar dynasty. However, from 1925 on, during the Pahlavi dynasty and especially after the Islamic Revolution (1979), Qom has transformed considerably in terms of size as well as internal structure, for example, through the addition of several radial streets (e.g., Azar, Chaharmardan) and axes (e.g., Ammar Yasser). After the Islamic Revolution, large migratory movements from north-western provinces of Iran (Markazi, Hamedan, Zanjan and East Azerbaijan) settled in the area north-west of the Qomrood river, the seasonal river crossing the city from south-west to north-east, increasing city size further mainly through informal urban development.

A typical Iranian historic city of the Islamic era was a cohesive whole divided into different neighbourhoods, belonging to different social classes, ethnic/religious groups or professions, which were physically connected and functionally related. Each neighbourhood had a centre comprising several different and interrelated elements, i.e., a bazaar, a local mosque, a square, a water storage system, and a workshop, according to the needs and social status of residents (Tavassoli, 2016). The neighbourhood had thus a vital importance not only physically, as a fundamental element of city structure, but also, and, more importantly, socially, as an intangible entity providing a sense of identity and bonding to local residents. The historic core of Qom consists of several of these typical neighbourhoods. However, new urban arteries built in the last century (Pahlavi dynasty and more rapidly during recent years) partially fragmented these recognisable units. More recent parts of the city, especially the new developments built in the last 50 years, following non-centralised, grid-like street patterns, are not based on the traditional neighbourhood but rather on more dispersed and repetitive structures. The ensemble of these changes result in a fragmented/complex urban form which still remains largely understudied.

The aim of this paper is to investigate such complex urban form through a novel quantitative method able to identify urban types across the entire city of Qom by, firstly, computing a set of 204 different descriptors, measuring aspects of the urban fabric and street network, and, secondly, by clustering this information through a hierarchical technique of cluster analysis, accounting for spatial constraints. The application of this method to the 200k+ plots and 35k+ street segments of Qom reveals 11 different urban types, six of which belong to recent urban developments (1975-1999), featuring more uniform/repetitive patterns of form, while the remaining five largely correspond to historic developments (1789-1975), featuring more fine-grained and diverse urban fabrics.

The morphometric approach

In the last 50 years, several methodologies have been developed to measure aspects of urban form. The most renowned are Space Syntax (Hillier et al., 1976) and the Multiple Centrality Assessment (MCA) (Porta et al., 2006), both measuring different kinds of centralities in street networks, capturing the potential use of urban space by city dwellers. More recently, researchers have introduced approaches that include not only metrics of the configuration of the street network, but also measures of plots, buildings, and blocks (Oliveira & Medeiros, 2016; Venerandi et al., 2018). However, due to the relatively small number of descriptors (less than 10), these approaches offer a limited description of the urban environment and do not identify different types of urban tissues. Latest advancements in this field considered more indicators (21) and applied Bayesian clustering to identify urban types at the metropolitan level (Araldi & Fusco, 2019). However, considering today’s data availability, the description of the urban environment is still somehow limited and the spatial unit (the street segment) for which information is aggregated is relatively coarse.

The morphometric approach presented in this paper is based on the quantitative characterisation of morphological patterns based on single measurable aspects of form. A single aspect represents a single dimension of the urban environment (e.g., plot area, street width, floor area ratio), while the combination of these aspects allows the detection of recurring patterns in the case study under examination. In this work, we apply the method proposed by Fleischmann et al. (2021) to detect types of urban form in Qom, through the morphometric characterisation of space. This technique is based on the concept of inclusion, resulting in a large set of indicators rather than a small predefined and potentially biased selection, combining information extracted from basic components of urban form to their local aggregations while retaining the finest level of spatial granularity possible.

Traditionally, this method relies on the use of two data inputs: buildings and street network. The former is also used to generate the spatial units of analysis, a Voronoi tessellation-based partitioning of the study area, acting as substitutes for cadastral subdivisions (plots). However, since reliable information on buildings was not available in Qom, we adapted the method to rely on plots and the street network (both provided by the local administration), skipping the artificial creation of Voronoi tessellation cells from building footprints. However, due to this constraint, we were able to compute only 51 of the 74 primary descriptors (those measuring aspects of plots, street network, and blocks). See Fleischmann et al. (2020) for reference. In terms of plots, we measured, for example, area, street/plot alignment, and coverage ratio (ratio between built-up surface and plot area). In terms of street network, we computed, for instance, proportion of 3-way intersections, street width, and local closeness, a measure of street network centrality, simultaneously assessing connectivity and proximity of street segments at the local scale (Porta et al., 2006). In terms of blocks, we calculated, for example, area, squareness, and granularity (ratio between the number of plots in a block and its area). A total of 204 contextual characters were then derived from the 51 primary descriptors, by computing mean, range, local diversity (Theil index), and homogeneity (Simpson index) of values at the local scale (third order of contiguity).

A clustering technique was applied to summarise this rich morphometric description and identify the distinctive urban types of Qom. However, differently from Fleischmann et al. (2021), we used a geostatistical technique that imposes a spatial structure on the clustering, drastically reducing noise and misclassifications within each cluster (or urban type in the context of this work). More specifically, we implemented the agglomerative clustering technique (Rokach & Maimon, 2005), a hierarchical method of cluster analysis, which builds a tree (or dendrogram) of clusters in a bottom-up fashion. Starting from the single observations, clusters are successively merged together to reach a main one. In this study, the merge strategy is based on the minimisation of the sum of squared differences within all clusters. The spatial structure is imposed by adding a connectivity constraint (only contiguous clusters can be merged together), through a third-order connectivity matrix. The optimal number of clusters (urban types) was assessed through the silhouette, a widespread heuristic technique for the validation of consistency in cluster analysis (Rousseeuw, 1987), and visual mapping of different clustering solutions.

Exploring the urban form of Qom through the morphometric approach

Datasets

The morphological analysis of Qom presented in this paper relies on two data sources: georeferenced datasets of the street network and plots. The former is a vectorial representation of street centrelines, cleaned of topology issues, for example, duplicates and false intersections. The latter is a vectorial representation of plots (cadastral parcels), cleaned of geometry issues, for example, duplicates and broken polygons. Both datasets were provided by the Municipality of Qom, the former dates back to 2019, while the latter to 2020. Both were available for the entire municipal area of Qom. However, due to inaccuracies in the periphery (single plots erroneously merged in one, absence of new roads), only the area circumscribed by the main ring road (Imam Ali highway) is considered in this study. This area consists of a total of 35,827 street segments and 227,165 plots.

Primary descriptors and contextual characters

Following the approach described in the previous section, we computed a total of 51 primary descriptors of the urban form and derived the 204 contextual characters, successively used as clustering inputs to identify urban types in Qom. In this section, for brevity, we present the primary descriptor floor area ratio at plot level (*sicFAR*), with relative contextual characters, as an example in Figure 1.

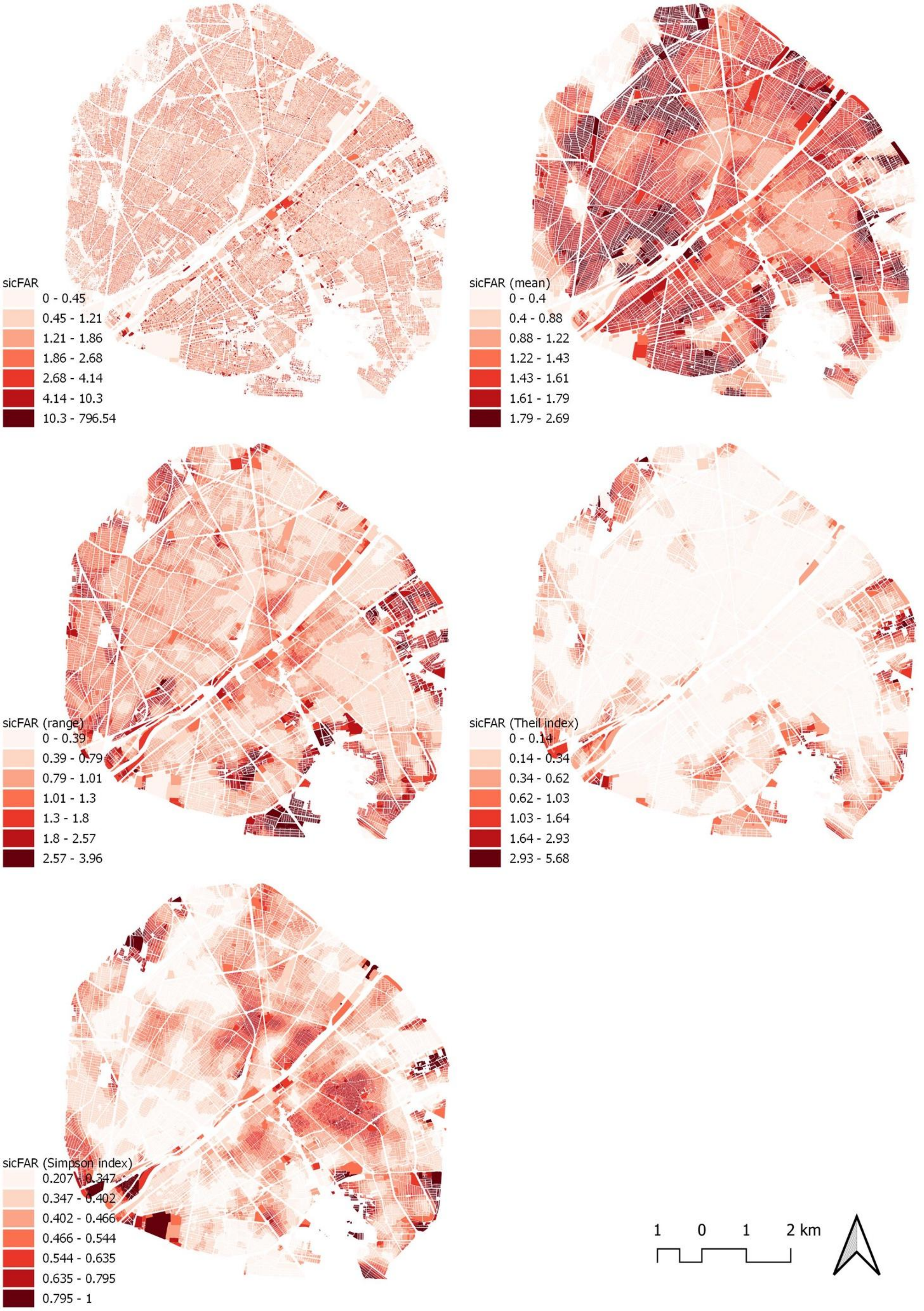

***Figure 1.** sicFAR (floor area ratio at plot level) in Qom (top left) with relative contextual characters (mean, range, Theil index, Simpson index) (from top right onwards).*

The primary descriptor *sicFAR* (Figure 1, top left), reveals a fairly uniform distribution of values, with the only exceptions being new neighbourhoods under construction with relatively low densities, located in the proximity of the main ring road, south-east, south-west, and north-west of the historic core, higher densities strips following main arterial thoroughfares (e.g. Imam Khomeini Avenue), and scattered plots with very high floor area ratios, corresponding to voluminous city landmarks (e.g. Imam Hasan al-Askari Mosque, Zamzam Mall, Salariyeh Business Centre). The derived contextual character *mean* reveals localised patterns of densities, showing how the western part of Qom tends to be more densely built compared to the historic core and the north part. The former, together with smaller areas in the south and east of the historic core, also shows larger local variations (*range*) of floor area ratios compared to the rest of the city. In terms of *local diversity* (Theil index), it strongly clusters in areas where urban development is still ongoing, where fully developed plots are intermingled with half-built or empty ones. In terms of *homogeneity* (Simpson index), the historic core and areas located north of it, corresponding to urban extensions dating back to 1969, show relatively uniform densities. However, the greatest values of homogeneity correspond to new peripheral high-density developments, with repetitive layouts, mainly located south-east, south-west, and north-west of the historic core.

The morphometric analysis of Qom

Agglomerative clustering was recursively applied to the 204 contextual characters of urban form to identify, through the silhouette technique, the optimal number of clusters (urban types) in Qom. Three possible solutions were identified: 4, 6, and 11. By visually inspecting dendrograms and colour coded maps of plots, which were assigned to their respective urban types, the solution with 11 was retained. The final dendrogram and the map of the urban types of Qom at the plot level, for different phases of urban development, are presented in Figure 2 and 3, respectively. Both are colour coded according to the level of similarity between urban types.

The first noticeable finding is the neat division between more recent urban types (left main branch of the dendrogram), roughly corresponding to the city development from 1975 to 1999, and the more historic ones (right main branch), representing the ancient core (Qajar dynasty) and further developments until 1975, underscoring the fact that 1975 was a turning point in city planning in Qom. To investigate this drastic change, we inspect the most relevant contextual characters in each urban type, starting from the left side of the dendrogram. Comments on the values of each contextual character relate to the average across the entire city. Urban type (UT) 4 (blue, Figure 2-3) is the most peripheral and thus the most recent of the set (1999). It is mainly characterised by above average variations in terms of coverage ratios, plot density, local diversity of building heights (averaged at the plot level), below average coverage ratios, buildings heights (averaged at the plot level), and local closeness, corresponding to an urban form in the making, featuring both completed street networks with fully built-up plots and more recent unfinished urban extensions, see, for example, Shah Seyed Ali (Figure 4, top left). UT 3 (teal, Figure 2-3) and 8 (light blue, Figure 2-3) come next in the dendrogram. Both belong to the latest development of Qom (1999); however, they are less peripheral than UT 4. UT 3 features an above average granularity of the urban fabric at the block level, homogeneity of block perimeters, node degrees, and a below average presence of cul-de-sac. UT 8 is characterised by above average homogeneity of number of plots per meter of street, plot complexity, diversity of plot areas, below average granularity and homogeneity of the urban fabric at the plot level, density of plots per block. Both UT 3 and 8 seem to represent relatively uniform city areas produced through top-down urban planning, see, for example, Jahanbini and Bokaii (Figure 4, top right). UT 10 (dark green, Figure 2-3) belongs to a relatively recent development phase of the city (1975). It features an above average rotation of plots and blocks towards 45° (with respect to the cardinal directions), homogeneity of number of plots per meter of street, diversity of plot areas and elongations, below average density of plots per block, seemingly corresponding to a semi-planned urban fabric oriented according to the Qomrood river, see, for example, Safaeiyeh (Figure 4, middle left). Next are UT 1 (green, Figure 2-3) and 6 (light green, Figure 2-3). The former is characterised by above average granularity and range of granularities of the plot system, mean and diversity of street segment length at three topological steps. The latter features above average diversity of block complexity, block perimeters, block areas, cul-de-sac lengths, and granularity of the plot system. UT 1 and 6 seem to be associated with a fine-grained residential urban fabric, produced through fragmented interventions, featuring the presence of large buildings (e.g., Ali ibn Abi Talib Hospital, Shahid Beheshti Hospital) and public spaces (e.g., Narges Garden). UT 7 (dark red, Figure 2-3) belongs to the right main branch of the dendrogram and thus to the historic types. It corresponds to the ancient core of Qom, consolidated during the Qajar dynasty (1789-1925). It is characterised by above average plot complexity and diversity of the same metric, reflecting a variety of plot shapes, and tortuosity of streets, indicating a layered/informal process of city building. UT 0 (red, Figure 2-3) largely corresponds to the development of Qom until 1969. It features above average levels and diversity of granularity of the urban fabric at the block level, local closeness, below average street canyon widths, indicating a fine-grained, well-connected, semi-informal urban fabric, see, for example, Darvaze-Rey (Figure 4, middle right). UT 5 (orange, Figure 2-3) is an exception as it is found across all phases of urban development. It is characterised by an above average diversity of plot compactness, granularity of the plot system, node degree, street front permeability, and below average local meshedness, corresponding to a mixed urban fabric featuring large buildings/public spaces intermingled with a more fine-grained/ordinary urban tissue, see, for example, the area including the Imam Hasan al-Asgari Mosque and the Imam Khomeini Grand Square (Figure 4, bottom left). Finally, at the rightmost point of the dendrogram, there are UT 2 (dark yellow, Figure 2-3) and 9 (yellow, Figure 2-3). They mainly belong to the 1975 expansion but can also be found in the latest expansion. The former shows above average diversity of height (averaged at the plot level) to width ratios, street canyon widths, homogeneity of plot compactness, below average node degrees and local meshedness. The latter features above average diversity of street front permeability, granularity of the urban fabric at the plot level, and coverage ratios, above average density of plots per block, homogeneity of cul-de-sac lengths. UT 2 and 9 largely correspond to city areas where migrants from the north-western provinces of Iran settled after the Islamic Revolution, creating a semi-informal mainly residential urban fabric, with more dendritic street layouts than the average neighbourhood of Qom, see, for example, Ali Abad and Sheykh Abad.

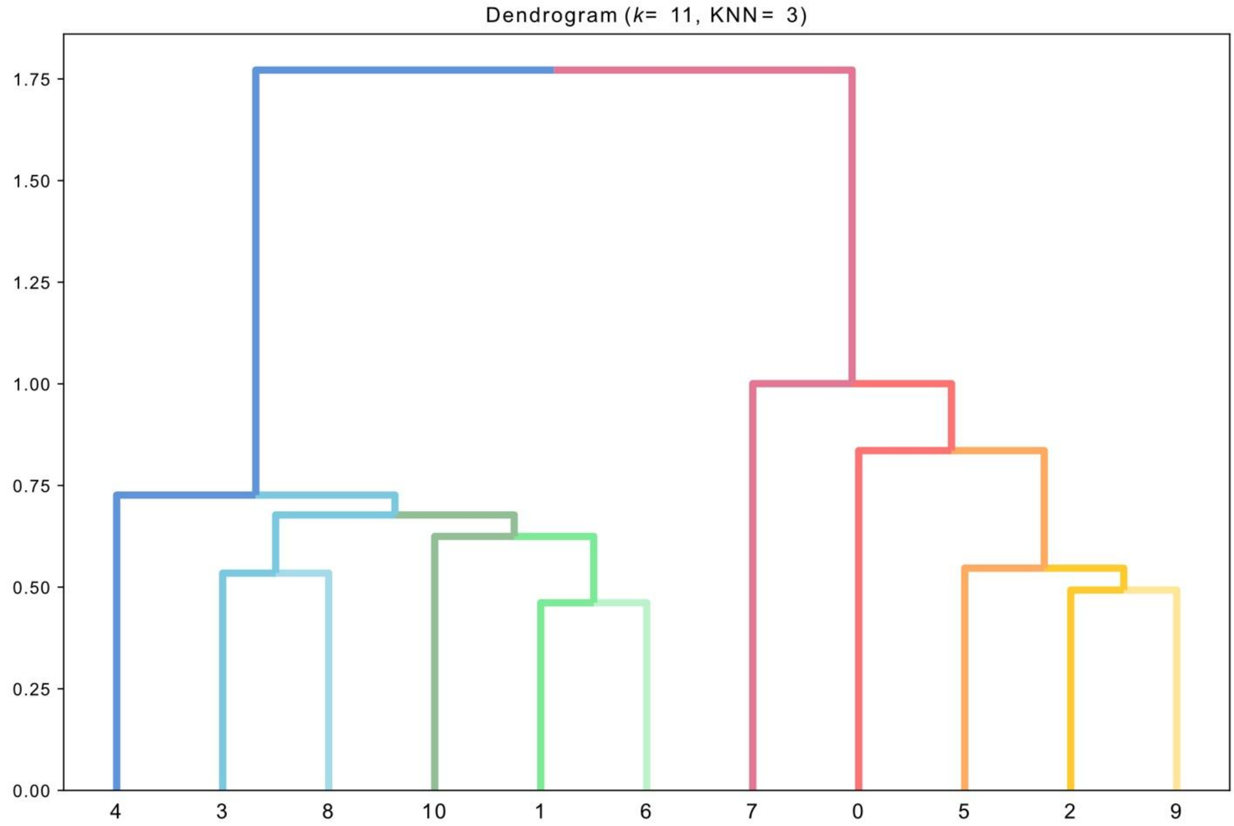

Figure 2. *Dendrogram of the 11 urban types of Qom, colour coded according to their level of similarity. Y axis represents Euclidean distances between urban types.*

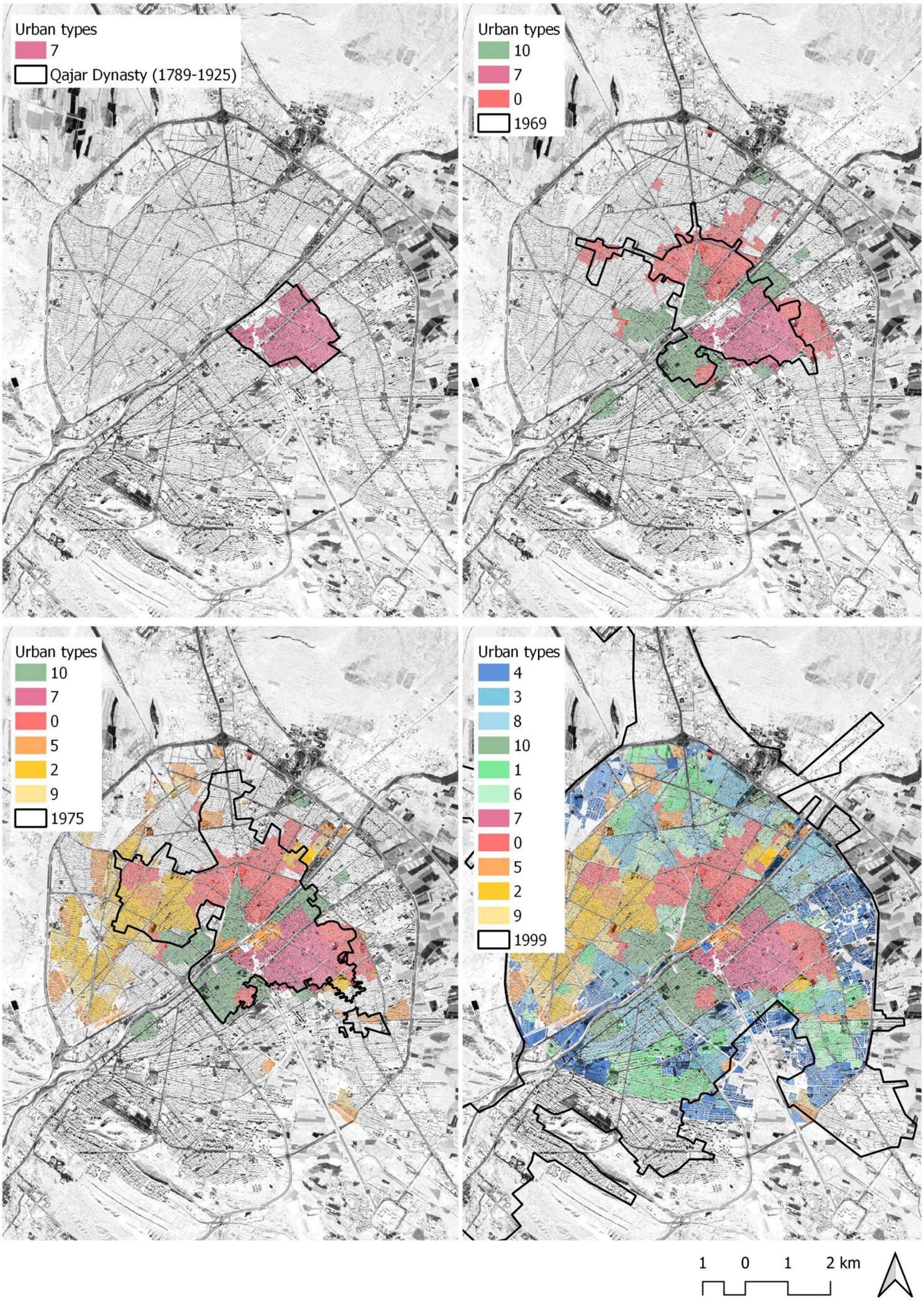

Figure 3. *The 11 urban types of Qom and main phases of urban development.*

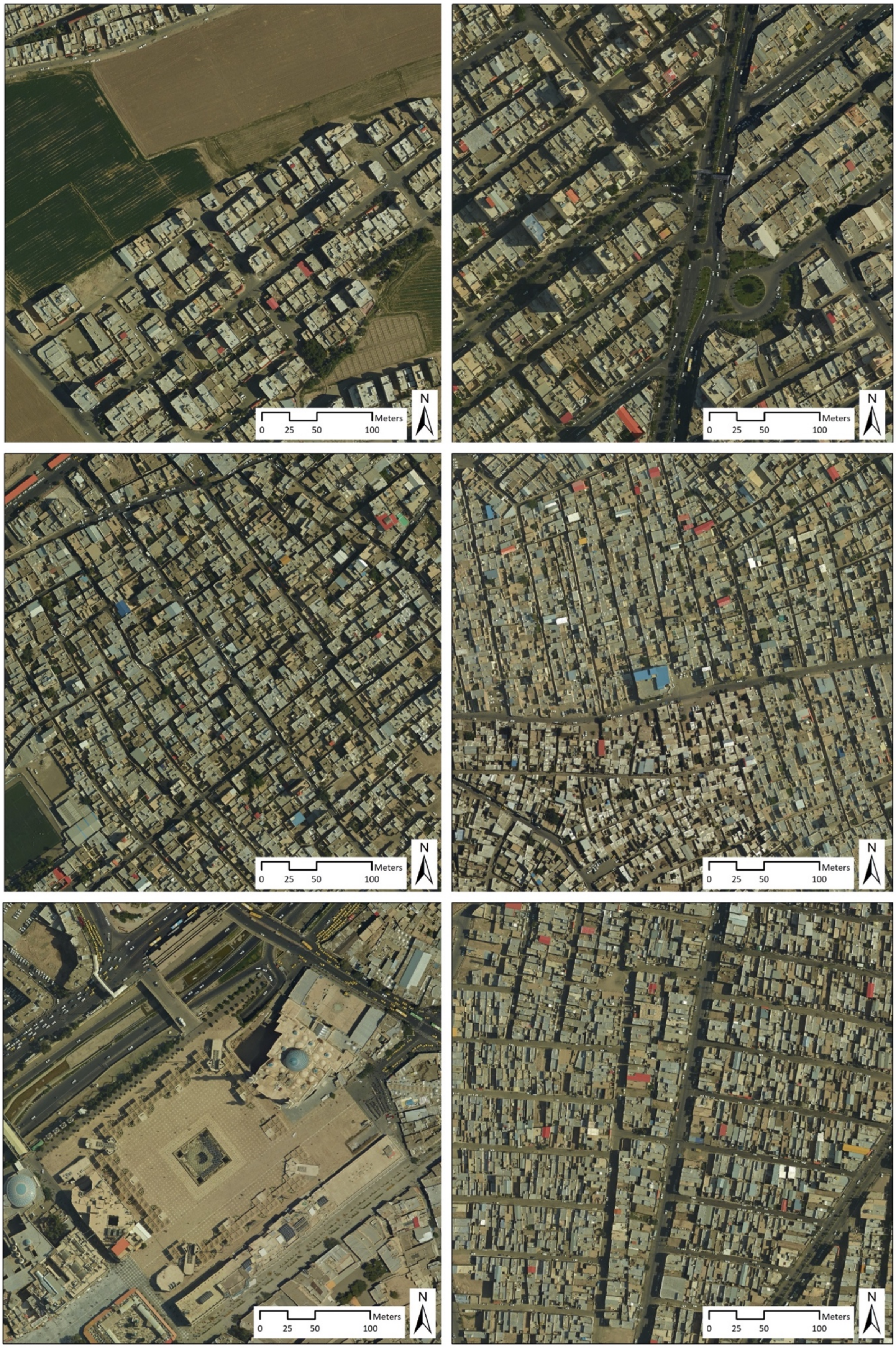

Figure 4. *Aerial imagery of a sample of urban types. Top left: Shah Seyed Ali (UT4). Top right: Jahanbini and Bokaii (UT 8). Middle left: Safaeiyeh (UT 10). Middle right: Darveze Rey (UT 0). Bottom left: Imam Hasan al-Asgari Mosque and Imam Khomeini Grand Square (UT 5). Bottom right: Ali Abad and Sheykh Abad (UT 2 and 9). Source: Municipality of Qom.*

Conclusions

Subsequent phases of urban development and decay stratified in the city of Qom, producing a complex urban form which is still largely understudied. In this paper, a novel morphometric approach is used to investigate such complexity and identify homogeneous urban types across the city. This novel approach is based on three main steps: (i.) measuring primary descriptors of form; (ii.) computing contextual characters by aggregating primary descriptors at the local level, through mean, range, local diversity (Theil index), and homogeneity (Simpson index); (iii.) clustering the contextual characters through an agglomerative clustering technique accounting for spatial constraints. 11 different urban types are identified by applying this approach to the contextual characters of Qom. The dendrogram associated with the clustering shows a clear distinction between more recent urban types (until 1999) and more historic ones (1789 to 1975), with the former being overall characterised by more uniform/repetitive urban fabrics, likely produced through top-down planning, and the latter featuring more compact and diverse urban fabrics, indicating informal/semi-informal urban development related, for example, to the settling of migrants from north-west Iran. The morphometric approach presented in this paper provides novel insights on the urban form of Qom, one of the main Iranian cities, and, at the same time, constitutes a replicable working example to investigate further case studies.

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