AUTOMATED RECOGNITION OF MORPHOLOGICAL PATTERNS IN URBAN OPEN SPACES

A. Peeters*, Y. Etzion

Desert Architecture and Urban Planning Unit, Department of Man in the Desert,
J. Blaustein Institute for Desert Research, Ben-Gurion University of the Negev, Israel
apeeters@bgumail.bgu.ac.il

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ABSTRACT:

Climate-urban form research tends to identify vernacular (traditional) forms as a successful combination of architecture, urban design and climate. This theory, which draws a parallel between climate and adaptive urban form, is supported by the accepted common belief that harsh climates, such as hot-arid ones, confront those who live in them with unique challenges. These challenges are answered by solutions that are continuously improved over generations by trial and error and therefore evolve into the "proper" response to the climatic conditions.

This paper is part of an ongoing doctoral research, which investigates the validity of this theory. Its aim is to study whether a systematic influence of climate on urban form development can be found, focusing on the design of urban open spaces. Towards this goal a quantitative methodology is adopted and a computer-based model of an automated recognition system is under development. This system consists of three main elements: an image processing element for recognizing urban open spaces, a pattern recognition element (developed in a GIS environment) for extracting and clustering morphological characteristics and a statistical element for determining the significance of patterns and evaluating their relation to climatic parameters.

The present paper introduces the methodology, which was developed to enable a substantial and statistically anchored evaluation of urban geometry in relation to its climatic context. It presents the first part of this methodology: the object recognition model, focusing on the definition of classes and class descriptors and the unique problems in developing a recognition system for urban open spaces.

1. INTRODUCTION

It is estimated that by the year 2030, 60% of the world's population will live in cities. In the more developed nations 75% of the population is already now urban (United Nations and Population Division, 2002). Urbanization will predominate humanity with all its implications. Today, more than ever before we are aware of the influence of city form not only on the quality of life of its inhabitants, but also on the environment beyond the physical borders of the city (Grimmond and Souch, 1994). Natural land-cover has been replaced by distinctly "urban surfaces" (Oke, 1987), which serve as the active interface in determining energy and water balances and in creating local conditions known as the "urban climate".

To reduce the negative aspects of urbanization on the microclimate within the city, it is important to understand the complex relation between climate and urban form. However, while the **urban form-climate** relationship has been extensively studied introducing numerical analysis, mathematical models, computer simulations and scale models (e.g. urban canyon and urban heat island studies), the reverse relationship of **climate-urban form** has been receiving a less systematic investigation, concentrating mainly on descriptive qualitative analysis of indigenous architecture. It is important to note that the order of words is not arbitrary, but denotes the relation of this study to the phenomena: either the influence of urban form on the microclimate or, vice versa, the influence of climate on the development of urban form, the latter being the focus of this research.

Several problems associated with existing **climate-urban form** research were identified. One of them is the tendency of existing **climate-urban form** research to present specific vernacular cases often situated in extreme climates, to demonstrate adaptive urban form. This is based on the assumption that traditional societies adjusted to environmental constraints, among them climate, through a process of trial and error (Mills, 1999). This theory has become so rooted in architectural philosophy and research that its validity has been rarely challenged. A number of studies, though, have questioned this assumption (Etzion, 1990; Roaf, 1990; Ratti et al., 2003). Another problem lays within the limitations of the qualitative narrative methodology that is commonly used in this type of research. Our criticism is based on the fact that subjective visual pattern recognition and a small number of specific cases limits the systematic and statistical basis needed in order to recognize significant patterns. This prevents the development of a decisive evaluation, which in turn constraints the formation of a substantial scientifically based theory. In light of this, it is apparent that the extent to which climatic conditions did influence city form does not need only further investigation, but rather a different type of investigation: a quantitative systematic approach that can measure the extent of the **climate-urban form** relation. Therefore the objective of the research is to develop a system that will not only recognize morphological patterns in urban open spaces in a systematic and accurate way, but will also determine whether or not a pattern's frequency in relation to climate is statistically significant.

* Corresponding author.

2. METHODOLOGY

In order to study systematically the influence of climate on urban form, a model of a hybrid system has been developed which fuses object recognition (classification), pattern recognition (clustering) and statistical analysis.

This study focuses on the recognition and climate related analysis of urban open spaces in vernacular settlements located in hot-arid regions. The definition of urban open space can vary depending on various aspects such as function, typology, ownership or morphological characteristics. The current research adopts a wider view that includes in the definition all of the spaces/voids among the buildings. This consists of all outdoor open spaces from the private residential courtyard to the public square.

The term morphological pattern is used in this research to refer to regularities found in the physical form, either in the geometrical properties or in the arrangement of objects in the built space or in both.

The system of inquiry is based on two sources of data: vertical, B/W aerial photos of vernacular settlements situated in similar hot-arid environments which serve as case studies and climatic data from local meteorological stations or - when such data is unavailable - simulated with the METEONORM (from ©METEOTEST) software.

GIS is utilized - first, to represent the complex urban space using a thematic layered representation for simplifying the complex urban system without loosing essential information, second, to extract the morphological characteristics of the various objects and third, to facilitate a cluster analysis for unsupervised pattern recognition.

Being based on aerial imagery, the proposed model must utilize image processing tools to interpret the images and convert image information inaccessible for GIS into a format that GIS can reason with, i.e. quantitatively extract morphological information. The potential of extracting information from aerial photographs makes them a valuable tool for urban form analysis particularly when no other accurate information exists (such as town plans, figure-ground maps and ground surveys) or is inaccessible, as is sometimes the case with vernacular urban settlements.

2.1 Structure of System

The developed model consists of the following three main elements:

a) An element that enables to recognize objects (types of open spaces) within urban form and classify them into their correct object class. This component is being developed using MATLAB®. This is a well-known programming language for technical computing suitable particularly for developing solutions for problems involving matrix representations such as images. The output of this component will be a stratified representation of urban form: different thematic layers, each one corresponding to a different class of open urban form.

b) An element that recognizes morphological patterns in the different classes and examines the significance of the patterns reoccurrence in the urban cluster. The output of this component will be attribute tables for each layer (object class). Each table consisting of a list of morphological characteristics and their values extracted using ArcGIS®. Following a cluster analysis these values will be grouped to form new classes, i.e. morphological pattern classes.

c) An element that can:

1. Determine statistically the frequency of occurrence (significance) of the recognized patterns.

2. Evaluate the relation between significantly recognized patterns and specific climatic criteria. An analysis of variance (ANOVA test) will be executed using a statistical package in combination with the GIS. This test will determine the frequency of pattern vs. a specific climatic criterion. If the relation between the two is found statistically significant, it will point to an existing link between climatic variables and urban form.

2.2 The Object Recognition Element

The following will present the initial steps to develop the first element; an automated system that can recognize urban open spaces based on aerial photographs:

The first step in designing an automated object recognition system involves usually a process referred to as training, in which the system "learns" to recognize the objects based on a set of examples known as the training set (Anil, et al., 2000). The Training set for this research consists of a number of aerial photos, which are used for predefining the object classes, building a library of shape properties (features that describe each class) and defining the classifiers (the rules and conditions for classification).

This step will be followed by an evaluation of the system's performance to determine the overall percent of cases, which were correctly classified (Mayer, 1999). Accordingly the features and classifiers will be modified to enable the most accurate class prediction.

Prior to these steps one must convert the aerial images into digital form and preprocess them. Preprocessing consists of procedures such as noise reduction, superfluous structure elimination, image enhancement, geometric transformations and if necessary image restoration. These operations are performed interactively and depend on the quality of the acquired images.

The use of remotely sensed imagery has become very common for the recognition of man-made objects such as buildings, roads, street greenery and agricultural fields. One of the incentives has been the potential of using these images for fast and accurate extraction of data related to man-made objects that could later be integrated into a GIS database (Lillesand and Kiefer, 1994). It is important to note that the process of recognition in the first research element stands for the ability of the system to accurately extract the objects and assign them to a correct predefined class, a process known as classification (Anil, et al., 2000). The method of classification can be used when prior knowledge about the shapes in the image exists, which makes it possible to predefine classes that consist of distinctive properties that will enable the automated system to discriminate between the shapes.

Therefore, the first stage in training the system in this study consists of pre-defining classes of open spaces and assigning to each class a set of descriptors, which will enable its most accurate classification. This step is a subjective non-computational process based on visual inspection and analysis of the images. Prior understanding of urban form and its components is fundamental to this step.

2.3 Class Formation and Representation

Object recognition is problem dependent. For example: features that are used for distinguishing between different types of open spaces are different from those, which are used for extracting buildings. Thus, prior to any image preprocessing it is important to study carefully the objects under question.

Although vernacular urban form appears complex, it is made up of basic elements that are often rather simple and regular, consisting of basic geometrical shapes, contrary to the irregular basic shapes often found in contemporary architecture. Therefore, one can assume a high degree of homogeneity in the built / un-built forms and group them into classes based on their morphology. A visual analysis of aerial images and figure-ground maps in hot-arid environments combined with a literature review on vernacular urban form in hot-arid environments was carried out. A number of urban form components were identified. These components consist of major elements that characterize urban form in general. They exist - all or in part - in a variety of urban settlements across the world, regardless of geographic location, differences in culture, religion, topography and social code. Naturally, differences do exist such as in building materials, design or architectural details. Figures 1 and 2 show examples of typical vernacular urban structures from different geographical locations, including the major urban elements that were visually recognized.

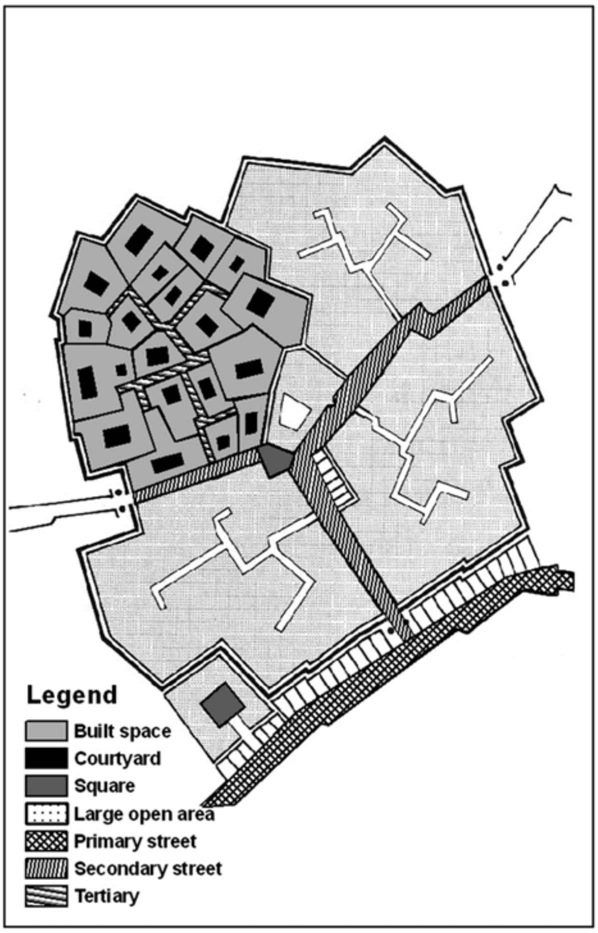

Figure 1. Identifying major urban elements in a typical vernacular urban structure of a North African city. Base map from *Urban Form in the Arab World*, pp.39 (Bianca, 2000)

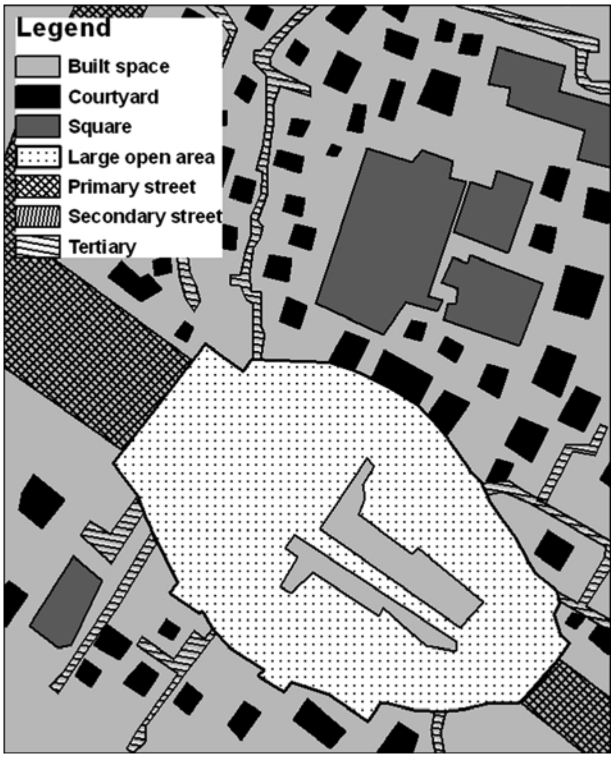

Figure 2. Identifying major urban elements in a typical vernacular urban structure of the old section of Yazd, Iran. Base map from *Design for Arid Regions*, pp.124 (Tavassoli, 1983)

The major urban elements that were identified formed the base for the class definition.

The objective was to form classes of distinctive types of open spaces. This was achieved by identifying key morphological features that could be detected visually and therefore would differentiate clearly between the classes, which would improve the prospects of an accurate automatic recognition. Table 3 summarizes the classes that were identified according to their typology.

Class	Typology	Built	Open
Built Space	Building	+	
Primary Street	Street Network		+
Secondary Street	Street Network		+
Tertiary Street	Street Network		+
Courtyard	Open Space		+
Square	Open Space		+
Large Open Area	Open Space		+

Table 3. List of classes

Comments on Table 3:

- All buildings regardless of function (residential, commercial, civic or other) were grouped under one class since they are not within the scope and focus of this study.

Built space consists also of walls and of open space, which is perceived as a built space in an aerial photo, such as a courtyard covered by a shading device or a semi-outdoor space e.g. an arcade.

– The division of street classes, based on morphological features is often parallel to their function. Primary streets are the main public networks of the settlement. Secondary streets usually lead from the main arteries to the residential quarters and are semi-public. Tertiary streets lead into the individual residential clusters and consist also of cul-de-sacs.

– The courtyard class refers to private open spaces within a residential unit. These include private gardens as well.

– The square class refers to a public space formed often as a result of an intersection of streets (Hakim, 1988) or within a neighbourhood centre.

– The large open area class refers to large public squares found usually adjacent to the civic or religious buildings. This class includes also public parks.

In order to represent a class within the environment of a computer it must be broken down into a set of descriptors. An example is shown in Table 4, which lists a selection of identified descriptors for the courtyard class. These features, recognized previously through the visual analysis, in combination with additional features identified through image processing, will represent and describe the classes for the actual object recognition. One must note however that while these descriptors represent most members in a class they cannot possibly describe all members, i.e. represent all probable variations. For example, there could possibly exist a courtyard, which is not quadrilateral and therefore might not be recognized by the system as a courtyard.

Class	Features
Courtyard	Closed polygon
	Enclosed by a building/buildings or by a wall/walls
	Quadrilateral shape
	Length / width ratio: 1:1 to 3:1

Table 4. Key features of the courtyard class

Additional descriptors will be added based on image processing to facilitate a better discrimination process. For example, it is possible to estimate the extent of an object's area or perimeter by visual analysis. However, the boundary of an object can be also automatically described in terms of its length. The automatic discrimination process is then based on defined thresholds.
Once the sets of descriptors are established for each class, rules for classification (classifiers) must be established and converted into the MATLAB® environment.

After the recognition system has been designed and its performance evaluated, it is possible to proceed to the application of the object recognition element. This consists of preprocessing all the aerial images and classifying the objects related to the study in each image.
Based on the classifiers that were defined previously, the objects will be placed in their respective classes (labelled). For example the courtyard class will consist of a layer portraying all courtyards that exist in the image.

2.4 The Pattern Recognition Element

External urban form is an expression of various forces and processes acting within and on the physical form. It can be analysed in terms of patterns or regularities, which can shed new light and understanding on the development of urban form. In recent years GIS has become a common tool for recognizing spatial urban patterns, it is extensively used for recognizing patterns related to human led processes such as classification of land use (Barr and Barnsley, 1998) or recognition of urban sprawl patterns (Sudhira et al., 2003). Consequently GIS can be used for analysing other spatial processes that have an impact on the physical urban form. Climate, for example, is an environmental spatial process, which might have an impact on urban form. In addition GIS layering can be used for representing and describing complex urban forms using the thematic layers, which were produced earlier in the object recognition element.
The techniques and tools of GIS can therefore be used in this research to achieve several objectives: represent in a simplified and visual method the morphology of the urban form, attach spatial properties and processes – object morphology and climatic conditions – to unique layers, and measure objectively the relation between a spatial process and a physical expression.

The output of the object recognition element consisted of thematic layers that represent the classes of recognized open spaces. Since the aerial photo has now been transformed into layers of simplified rasterized forms, these can be accurately vectorized using a raster to vector conversion software (either external or within the GIS environment).
A vector topology makes it possible to build a morphological database, since morphological attributes characterizing each form in each class can be extracted. Information such as dimensions, symmetry, density and proportions can be obtained using GIS tools. Using these basic extracted properties, it is possible to identify urban form parameters that directly link urban morphology and climate, orientation for example. This database, consisting of an attribute table of morphological features for each layer, serves as the basis for the pattern recognition.

While the previous element used the method of classification or supervised pattern recognition to recognize objects, the second element uses an unsupervised pattern recognition method known as clustering.
In the supervised method the objective is to "teach" the system to classify a set of known classes based on previous knowledge. Clustering on the other hand is valuable when prior information does not exist i.e. one is looking for new patterns (classes). Clustering is based on finding natural trends within the data according to values of exhibited features. New classes are formed accordingly, which can shed new insights on the data. Clustering can be performed using a statistical package in combination with the GIS environment.

Various algorithms for data clustering have been developed which are based on similarity / dissimilarity measures. These represent the degree of natural association between patterns in a class. The exact type of clustering algorithm will be defined as the research progresses.

2.5 The Statistical Analysis Element

The statistical analysis consists of two parts:
The aim of the first part is to determine whether the patterns (new clusters) are significant. This can be tested using well-established statistical significance tests, for example by calculating the frequency of occurrence (Etzion, Portnov et al. 2001).
The aim of the second part is to examine whether the layout of the significant morphological pattern, which was identified in the first stage of inquiry, was probably affected by climatic considerations. To achieve this, the relation between this morphology and the accepted climatic criteria (such as orientation, solar exposure etc.) must be established. Following this, the significance of the occurrence of this relation will be determined within the set of the members of that morphology.

A climatic criterion is a scientifically established principle, which defines the preferences and solutions for achieving a climatic responsive planning and design. For example the preferred values of height/width ratio that are recommended for solar exposure.
To select the climatic criteria for the specific locations, climatic data will be collected and added to the database. This will include seasonal air temperatures, wind direction and solar radiation (intensity and angles). The data will be obtained from local meteorological stations or by using a computer simulation software such as METEONORM.
Subsequently, the recognized patterns will be linked to the suitable climatic variables, for example orientation to intensity of solar radiation.
The final step is then to determine whether there exists an observed relationship between the two sets of variables: the set of recognized patterns and the set of selected climatic criteria. The statistical level of the observed relationship can be assessed using an Analysis of Variance test (ANOVA), which evaluates the frequency of a pattern vs. specific climatic criteria. If the relation between the two variables is found statistically significant, it will point to an apparent existing link between climate and urban form.

3. DISSCUSSION AND PROGNOSIS

Developing a system for automatic recognition of open spaces involves a set of unique problems:

- Open polygons: As opposed to buildings, open spaces are often characterized by open polygons (excluding the courtyard class). This suggests that segmentation based on edge techniques will not be sufficient. Therefore a combination of external (boundary) and internal (shape) properties is important for characterizing and representing the objects.

- 3D information: The third dimension is an important parameter in the **climate-urban form** relation. It is essential for calculating morphological characteristics such as height/width ratio and urban parameters such as sky view factor. Height can be obtained using existing algorithms that derive building heights from shadows. Prior to this, one must automatically recognize the shadows in the image. This means that the images must contain clear shadows of buildings. However the existence of shadows in the image might interfere with the process of recognition.

- Green spaces: The basic assumption is that vernacular urban settlements in arid areas are characterized by a continuous built fabric (Bianca, 2000). This means that green open space was often compacted and kept to a minimum consisting of well-defined small private gardens or public orchards. Large green spaces were rare, as well as undefined public open space. The existence of greenery might pose problems in the recognition process since homogenous appearance of open spaces is crucial for correct classification. The solution might be to develop sub-classes of green areas.

- Other urban form determinants: Urban form is a result of various determinants. It is impossible to overrule others in favour of one such as climate. An insignificant result in the ANOVA test will suggest that there are other determinants overruling climate. These will be only speculated upon in the scope of this research. However, a similar model can be applied in future research to study quantitatively other urban form determinants.

Sustainability calls for urban form that is site-specific - i.e. relates to its climatic context among other things. However, it is not enough to conclude that traditional societies produced site-specific urban form and that we should follow in their footsteps, based on a few demonstrative examples. Developing a system that can realize this goal will establish or refute this existing theory. In addition it will provide the **climate-urban form** studies with an archetype of an automated system and with an extensive database that can be used for future analysis in other studies of urban form.
Open spaces are believed to potentially modify – for the better or worse - negative aspects of urban climate. In order to realize this potential for the better and avoid uncritical use of vernacular patterns in contemporary planning, it is essential to understand the complex system, which hides behind the patterns.

REFERENCES

Anil, K. J., Robert, P. W., Jianchang, M., 2000. Statistical pattern recognition: a review. *IEEE Transactions on Pattern Analysis and Machine Inteligence*, 22(1), pp. 4-37.

Barr, S. L., Barnsley, M. J., 1998. Application of structural pattern-recognition techniques to infer urban land use from ordnance survey digital map data. In: *3rd International Conference on GeoComputation*, Bristol, UK.

Bianca, S., 2000. *Urban Form in the Arab World*. Thames & Hudson, London.

Etzion, Y.,1990. The thermal behaviour of non-shaded closed courtyards in hot-arid zones. *Architectural Science Review*, 33(3), pp.79-83.

Etzion, Y., Portnov, B. A., Erell, E., Meir, I., Pearlmutter, D., 2001. An open GIS framework for recording and analysing post-occupancy changes in residential buildings – a climate related case study. *Building and Environment*, 36, pp. 1075-1090.

Grimmond, C. S. B., Souch, C., 1994. Surface description for urban climate studies: a GIS based methodology. *Geocarto International*, 9, pp. 47-59.

Hakim, B. S., 1988. *Arabic-Islamic Cities: Building and Planning Principles*. Kegan Paul Ltd, London.

Lillesand, T. M., Kiefer, R. W., 1994. *Remote Sensing and Image Interpretation*. John Wiley & Sons Inc, New York.

Mayer, H., 1999. Automatic object extraction from aerial imagery – a survey focusing on buildings. *Computer Vision and Image Understanding*, 74(2), pp. 138-149.

Mills, G., 1999. Urban climatology and urban design. In: *The 15th International Congress of Biometeorology and International Conference on Urban Climatology*, Sydney, Australia, pp. 541-544.

Oke, T. R., 1987. *Boundary Layer Climates*. Taylor & Francis Group, London.

Ratti, C., Raydan, D., Steemers, K., 2003. Building form and environmental performance: archetypes, analysis and an arid climate. *Energy and Buildings*, 35(1), pp. 44-59.

Roaf, S., 1990. The traditional technology trap: stereotypes of Middle Eastern traditional building types and technologies. *Trialog*, 25, pp. 26-33.

Sudhira, H. S., Ramachandra, T. V., Jagadish, K. S., 2003. Urban sprawl pattern recognition and modelling using GIS. In: *Map India 6th Annual International Conference*, New Delhi, India.

Tavassoli, M., 1983. City Planning in the Hot, Dry Climate of Iran, In: Golany, G. S., *Design for Arid Regions*, Van Nostrand Reinhold Company Inc., New York.

United Nations and Population Divisions, March 2002. *World urbanization prospects: the 2001 revision*, Report ESA/P/WP.173, United Nations, New York, USA.

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