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A GIS for the homogeneity assessment of urban fabrics

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The paper presents indexes for homogeneity assessment of urban fabrics and the structure of the GIS which allows to compute them. The computation let us compare between several urban designs and can be used as decision support instruments.

Since the beginning of the 1980's, urban regulation has been commonly considered as the very last instrument of homogeneity production. When reading some French regulations (the POS [MAIRIE.,1989]), it appears that one of the most important concern of the urban designer is to set up a morphological maintenance of order, a duplicator of morphological traits, which gives to town, for policing, for urban hygiene or for aesthetic reasons, its visual "identity", its unforgettable "imagibility". It seems also that rise of regulation was linked to the hypothesis disclosing the efficiency loss of classical factors in homogeneity production throughout the second half of the 20th century. This hypothesis has been verified by several urban morphology studies [LAISNEY, 1987; HAROUEL, 1983].

Through steadfastness of plot conditions at first, then regulation and construction ones, those researchs (and more generally all classic morphology researchs ) have explained the existence and the emergence of "types" (type of building, of plot configuration, etc.) which are peculiar to some urban fabrics. For some authors, the urban structure had to be defined as an agglomeration of similar buildings (in relation with the street) (CANNIGIA, MARETTO). For them, the urban fabric (also named plan unit [WHITEHAND, 1981]) is identifiable by its homogeneity (SAMUEL, WHITEHAND) and by the repeatability of the forms (BAIRD) it contains (in [CHOAY, MERLIN & al., 1986]).

Whatever the chosen definitions, the classical urban morphology pursues the repetition of "similar traits", of "typical traits" [MURATORI, 1959]. The analysis methods used by this discipline have been developed in the 1950's in Italy and became systematically used in France in the 1970's. Since then, they are absolutely necessary before any urban design or any regulation making. Those methods have also contributed in the design of quantitative methods which have unfortunately never been used in an operational way. In France, many authors have used quantitative methods [CMMI, 1972] [MAROY, PENEAU, 1973] [DARIN, 1981]. Besides, those methods did not think over the complexity and the variety of forms that could be found in an urban structure. In order to integrate this complexity to the analysis, we have proposed a model which assesses automatically the urban form homogeneity [MAIZIA, 1998]. This model may help the urban designer to analyse the urban form and to protect it (or to transform it) according to design targets. Before describing the assessment protocol, we will recall the theoretical foundations that constitutes the logical structure of the GIS. One may find more information in [MAIZIA, 1999(a)]. The GIS is built thanks to both formalisations. On the one hand, the urban fabric is modelled as a graph according to the graph theory. On the other hand, the "quantity" of homogeneity is given by two indexes.
named morphological deviation and rate of irregularity. Let us present briefly these formalisations.

**The urban shape model:**
The urban shape has already been modelled in graphs [DUPAGNE, 1997; DUPRAT, PAULIN & al, 1995; VAN LEUSEN, 1996]. All these modelisations have allowed to identify logical structures of the urban and architectural space and have revealed some logical rules of the space composition. But none of them has really permit to analyse the urban form in both topological and geometrical way (morphological way). That is the reason why we have proposed the following procedure. In our protocol [MAIZIA, 1999(b)], the urban form is decomposable in systems. Each system is defined in a semantic way. For example, one can describe a building looking to its windows as a system of windows, its roofs as a roofing systems, etc. According to this, one can postulate that the urban fabric is simply a set of systems or, more rigorously, a system of system (a meta-system). Each system is himself decomposable in elements and in proximity relations. Finally, an element can be assimilated to a loop/arc *dextrorsum* drawn as shown in FIG[1]. The position between elements is given by a Delaunay’s triangulation made on the set of centroïds. In order to assess a system homogeneity, or to compare the elements’ form taking into account the relative position between them, we have compared their boundary respecting a rigorous protocol. To make this comparison and to quantify the difference between elements, we had to put them in a particular orthonormal reference mark as shown in FIG[2]. After this operation, each element was formalisable in a three column matrix where each column represented the Euclidean co-ordinates of the points which make up the boundary. ($A^j_i$)

Thus, the mathematical expression of an objet might be written as:
We might then calculate a "mean" object represented by the mean outline:

\[ \overline{\text{Obj}}_{ij} = \begin{bmatrix} \overline{A^1_{ij}} \\ \vdots \\ \overline{A^k_{ij}} \\ \overline{A^N_{ij}} \end{bmatrix} \]  

We might then compute the mean distance between each object and the mean object. This distance was called morphological deviation:

\[ e_{ms} = \frac{1}{N \cdot T_s} \sum_{i=1}^{N} \sum_{j=1}^{T_s} \left\{ \frac{q_{ij}^e \cdot \overline{A^j}}{P^m} \right\} \]  

where:

- \( T_s \) gives the system size while there is no sample; \( T_s \) is generally the number of analysed elements;
- \( N \) is the number of points which belong to the outline and which result from a systematic sampling (the sampling of points is made from an outline cut-out in equal segments). The unit distance obtained by the ratio \( P_m/N \), where \( P_m \) symbolises the mean perimeter, is called resolution. The error margin is given by the ratio resolution on mean perimeter (or, more simply, the precision is equal to \( 1-1/N \));

The disadvantage of this index is that it does not inform about the extent of a morphological difference but only about the size of the difference. A deviation of many meters for a small number of elements with a small outline is not at all comparable to the same deviation value concerning a vast set made of very large elements. A relative value has been proposed and called irregularity rate. This rate expresses one quantity as a function of the morphological deviation \( e_{ms} \), of the mean element perimeter \( P_{ms} \), and of two other parameters determinable with precision by a psychological research. Its expression is:

\[ \tau = 1 - e^{-\frac{e_{ms}}{P_{ms} \cdot (1-e^{-T_s})}} \]  

where:

- \( e_{ms} \) is the morphological deviation;
- \( P_{ms} \) is the mean perimeter of the mean object;
- \( T_s \) is the system size - that is the number of objects that a system \( S[k] \) contains;
- \( e=2,718 \).

\( ts \) is equal to 0 when the regularity is perfect and goes to 1 while irregularity increases toward infinity.

To compare regularity of several systems, we have weighted the irregularity rate with the relative area \( Sr \) of each system (the ratio between the system area and the meta-system one). We obtained the formula:

\[ Dts = Sr \cdot ts \]  

The GIS structure

Let us describe now the GIS structure. Each system is recorded as a coverage. The superposition of coverage allows to re-build the whole urban meta-system. For many technical reasons, we have chosen to record each element as an ASCII file containing all the
data necessary to compute the indexes. Those files which comprise informations about area, resolution and vertex relative co-ordinates, are stocked in an organised database. Their name gives the code of their address in the meta-system. The programs which compute the indexes are written in C++ language and joint up to MS-DOS® or UNIX® routines. The results are stocked in files exportable towards the mapping module. The HTML programming sets up the GIS in objects linked with hyper-links. From a coverage map, it is easy to visualise the whole street vertical section, to display the view of the buildings from the street, or to make calculation of the morphological deviation or the irregularity rate. The friendliness of the HTML navigation enables to join the calculation with the visualisation and to easily make several comparison between several architectural or urban designs. It helps the urban designer in the choice of different designs. The general structure of the GIS is described in FIG[3]

![Fig. 3](image)

The computation module output may be exported without difficulty in expert systems for building reference database. They may be also integrated in decision support software (as Townscope® software).

**Examples of computation :**
The results' relevance depends at first on the relevance of the selected area. One may choose the building, the block, the street, the place, the district or any other sector as the assessment unit; one may even use the sector delimited by the pedestrian field of view or by a stereographic projection (as it is propounded by Townscope). The unit area depends on the analysis scale and the design targets.

Following are some examples of computation using as unit the building FIG[4].

As told, this sort of computation is useful for comparison.

Indeed, the calculations are workable thanks to the symbolisation of the meta-system regularity in the following matrix:

\[
\begin{pmatrix}
\end{pmatrix}
\]

where the components are the rates of irregularity of each system.

The law of architectural or urban morphological integration may be referred to the law of matrix \(\xi\) conservation. If \(\xi\) is still constant after a design insertion, one may deduce that the integration (according to this protocol) is perfect. The variation of \(\xi\) allows to evaluate the "quantity" of integration. Of course this sort of assessment can not be took as a standard. The urban designer can weight the rates or the matrix in the integration equation to make it more sophisticated, operational and consistent with the goals that he has defined beforehand. This
method enables him to build consensual definition and to ensure the decisions’ reproducibility (as for building permit decisions). The following figure FIG. 6 presents a way to make comparisons between several propositions.
Conclusion
As it has been shown, cities are distinguished by a certain morphological homogeneity and one of the local authorities role is to protect this homogeneity by prescribing plain architectural and urban rules for designers. The result depends at first on the planner rules understanding and on his strictness in applying them. But one may admit that it is more difficult to apply qualitative rules than quantitative ones. For instance, density rules are easier to apply than aesthetic ones. This is one of the reasons that led us in proposing a method which uses quantitative language as a model of description of urban fabrics morphological homogeneity. In a practice purpose, those models may be used as prescriptive ones. For instance, urban planners and urban designers may assess a building integration in its context. To protect an urban fabric, they have to verify that the rates value remains constant after the building insertion or after the urban design achievement.

In an analytical purpose the calculation of those indexes helps the research worker and the urban designer to reveal the real part of morphogenerator factors which produce urban form. It may assess the architectural and urban rules part.

As well, this short paper brings us to think that the variety of those applications (and we can imagine other ones) shows a large potential audience of automatic instruments. It also affirms, paradoxically, that their unpleasant language can lead to the opposite situation and then to a formalisation renunciation.

With the help of computer and GIS technology (and the HTML navigation) one may make calculation without knowing in details the mathematical contents of the calculated indexes. This is probably their first advantage. However, it is to be feared that the loss of these knowledge contents might be followed by a loss of the meaning contents. This is certainly their first danger. The farther the indexes are far from the reality, the greater the danger. To prevent this danger, we have proposed in those lines indexes which we hope close to morphological reality and to the designer’s concerns. Now, it is time to hope that morphologists will be convinced of their usefulness...

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