Advanced tools and algorithms for parametric landscape urbanism

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In the last decades, urban design has been influenced by its relationship with landscape. This has led to a new approach formalised and called Landscape Urbanism. Defining specific reading and analysis instruments together with proper design methods, capable of a transdisciplinary dialogue with geography, plant and biological world’s languages, landscape urbanism can undoubtedly obtain more performing purposes than the ones achieved by traditional urban planning. Moreover, new digital tools are appearing, providing urbanism with new instruments for an advanced and interactive way to design cities in close relationship with landscape. The process starts with the acquisition of large quantity of data, like georeferenced maps in conjunction with relevant information about the territory, such as traffic and atmospheric pollution data, important buildings and monuments or significant landscape elements (rivers, mountains, etc.). All this information is combined onto multiple layers in order to be used by different design algorithms, connected by multi-dimensional arrays, whose reciprocal relations are dynamically controlled by architects and engineers. We will present here the case study of an ecological and regenerative infrastructure for the city of Bergamo designed on the basis of these principles, using a convenient combination of parametric tools.

Keywords: algorithmic city planning, landscape urbanism, post-urban architecture

INTRODUCTION

During the last two decades, the idea of landscape has been assumed as a generative model for urban design. This concept has been proposed and supported not only by a great interpreter of contemporary architecture like Rem Koolhaas, but it has permeated a large number of theories worldwide that are constituting a disciplinary advancement along this path. Perhaps, the most complete and interesting work on the historical and disciplinary formalisation of such approach is due to Charles Waldheim (Waldheim 2016), who himself defined it as Landscape Urbanism. This is why the perspective from which we look at the interface between engineering and ar-
chitecture leads us to recognize urbanism, and especially landscape urbanism, as the exemplary place of such disciplinary hybridization. An inhabitable future for that urban environments that we call post-urban - not only the traditional peripheries but also suburbs and new conurbations of larger towns - is possible only by devising and designing new eco-infrastructural systems, infrastructures for urban regeneration, multitasking infrastructures, systematic Green, living accessibility, etc., and a de-engineering building process that can recover the disorder of empty spaces, non-places, and sites of a lost naturalness. And what could be the tools allowing us to achieve these purposes, other than those managing georeferenced maps, and parameterizations of geographical data, in combination with additional algorithmic tools to control the growth of cities? In our case the latter are some tools that have been developed in engineering for structural form-finding applications, the popular parametric 3D modeling software Rhinoceros and Grasshopper with plugins like Elk and Meerkat. These tools, used together, contribute to define the so called Parametric Urbanism. There can be several ways for these meta-objects to connect with each other (Otto 2009). A rule based on their reciprocal distance can be defined, or a model of their distribution on a surface can be identified in a similar way. Their density can be hypothesised depending on the type of the studied object (human being, animal, building, etc.), and so on. In addition to bi or three-dimensional distributions, it is also possible to consider and conveniently model the behaviour of people, animal or other “unpredictable” beings, organised in single entities or in crowds, like in (Waldrop 1993) and (Canetti 1984). All this information is then converted into mathematical objects. The effectiveness of the entire procedure relies on the accuracy of the various mathematical models and on the way they interact with each other. The methodological part of this work derives from the chapter “A-Astrazione/E-Strazione: Per una metrica qualitativa dello spazio urbano” written by V. Paris in (Pizzigoni 2017). This study starts from the analysis of the city of Bergamo and its relation with the territory, seen through the presence of the Morla river that becomes the element through which the entire regenerative process can begin.
THE SEARCH FOR AN OPERATIVE METHOD
The chorography of Morla river, with both its natural and urban topography, characterizes not only the place and the space, but it also becomes the founding element of all produced maps. The adoption of different viewpoints identifies different narrations that can be far from each other in many respects, but that share three factors: two physical - the urban area and Morla’s hydrography - and one operational. The development of the latter needs our attention [1], and this research is focused on the identification of design strategies capable of abstracting and extracting data in order to reveal and represent hidden relations inside urban space. First of all, it must be defined the meaning of the term strategy and the concept of procedure, the latter being the basis of the strategy itself. A procedure must be intended as an algorithm, whose scope is the description and the virtual representation of a physical, social or environmental phenomenon. Every procedure is constituted by a logical sequence of mathematical operations and it possesses specific variables, input and output. In particular, it should be capable of restoring the consequentiality of all the elements that represent physical phenomena or real entities. With the term strategy we refer to a vision (see Figure 1), a priori defined through a series of subjective choices and strictly related to the design process and to the concept itself. A strategy identifies one or more procedures that are related to each other. This approach implies the need to develop complex readings and analyses, creating logical connections between them in order to provide a better comprehension of urban phenomena. Every logical step has to be made explicit in a formula, in a mathematical model or in a sequence of smaller steps. In order to achieve this, it is requested a description of the city’s social and evolutional phenomena which should be beyond a simple static representation. The adoption of such a methodology shifts the design effort to a more abstract level, where connections, networks, time and places of diversities become dominant. We are required to operate on two different levels. A first abstract and methodological level, containing a set of verified procedures, capable of obtaining a result. A second level, seen as a synthetic model, recalling a Batty’s definition (Batty 2007), represents the bridge between real and virtual and must be capable of foreseeing all possible scenarios with good accuracy.

PROCEDURE
In theory, every procedure can be specified in three phases: reading, analysis and processing (see Figure 2). The algorithms that constitute its single steps should have some common characteristics in order to verify their congruity through some form of output in every moment of the process. Other properties may belong only to specific situations. As previously said, procedures are algorithms with a precise purpose, describing and composing traces deriving from acquired data. Given these conditions, a natural question is: what should be the task of a designer? Where should its individual actions and technical skills take place? The efficiency of this phase of design work depends on the current knowledge in computer science and architecture, but the possibility of describing the complexity of urban space needs skills in several disciplines which are barely capable of interfacing with each other. As an example, it can be noted how difficult can be the interaction between architectural design and structural engineering, so strictly connected in the traditions of the past. Ability of comprehension, dialogue, synthesis, sensitivity for the reading of the present, are fundamental and necessary gifts not only for the single designer, but especially for heterogeneous working groups, where different and complex skills have to dialogue, interact and deal with each other in order to pursue a common goal.

THE MAKING OF A PROCEDURE
The first phase of this study is about the reading and the analysis of regional [2, 3] and municipal [4] open data, integrated with the ones coming from OpenStreetMap (OpenStreetMap 2017). The gathered information is managed by algorithms capable of providing a numerical or graphical representation. In
particular, the research is focused on the determination of an ordered set of instructions whose aim is the correct reading of shape file [5] or spreadsheet data. This choice has been followed because the former represents the standard for GIS systems, so these procedures can acquire data and use them in georeferenced environments. At the end of the reading phase, for simplicity’s sake, we can imagine that data are organized in different layers, each of them corresponding to different classes of elements. Later, at the analysis stage, the needed information is extracted and organised in order to achieve the objectives defined in the strategy adopted by the designer. At last, every procedure is characterized by the processing logical-sequential group, constituted by algorithms which have the goal to relate layers one to each other. This last phase necessarily needs to produce a graphical output.

STRATEGIES: EXAMPLES AND CLASSIFICATION

We present some examples derived from the different strategies adopted during this research, stating their objectives and describing some details. The first strategy here considered deals with the analysis of the entombed parts of the Morla river (see Figure 3). This strategy is based on three procedures. The first one, whose scope is the materialisation of the chorography of the surveyed area, retrieves the layout of the Morla and of the built environment from a shape file (reading phase). Afterward, it extracts from the previously obtained data a series of points, or nodes, and organises them in layers (analysis phase). Finally, nodes are adequately connected to each other those nodes in order to materialise the buildings and the Morla’s riverbed (processing phase). The second procedure, similar to the first one, acquires the information related to the covered sections of the river, providing their geometry. The third procedure collects the data about the outflow and the flow rate of the river (return period of 20 years) and it represents them by a series of diagrams. Together, the three procedures give an overall view of the state (quantitative and qualitative) of the entombed parts of the river inside the urban environment. In this case, the adopted strategy has a purely informational function. Other procedures have the aim to identify temporal phenomena and criticalities through the processing of layers and their data.

After this first and simple strategy, we present two more strategies, less simple, that can determine the buildings total volume and urban density (see Figures 4 and 5). In each case, a survey has been run by adopting a support matrix, constituted by 100 metres wide square cells, which have allowed us to read and analyse specific phenomena. The adoption of this grid allows us to focus the attention on the very subject of the survey (buildings total volume and urban density), filtering the unnecessary elements. In this way the diagram represents only the geographical distribution of a specific element. The first of these two strategies divides the total volume of the buildings contained inside a cell by the cell’s area.

Figure 3
Strategy: analysis of the entombed parts of the Morla river. On the right column it can be observed the ratio between the outflow and the flow rate of the river (return period of 20 years). It can be noted that five of six sections are undersized.
Figure 4
Strategy: determination of the total built volume in a given area. The diagram shows the zones where the ratio between built volumes and relative area is more than 15%. Regions with greater population’s concentration can be easily found.

Figure 5
Strategy: evaluation of urban density for a given area

In the figure, every element of the grid assumes a different colour in relation to this ratio. In particular, completely red elements correspond to the highest ratios. If we look at the diagram, the cells identifying the ancient part of Bergamo, constituted by small-medium buildings being very close to each other, are red. The cells containing big and isolated buildings are in a similar condition, being also coloured in red.

The next strategy (see Figure 5) is aimed at the representation of the urban density. As for the previous case, we use a support matrix with 100 metres wide square cells. Their colour changes according to the number of buildings belonging to each of them. In this way, it is possible to distinguish between historical and recent buildings. This property derives from the characteristics of the procedures and their combinations for the strategy’s tuning up. For a better comprehension of what it has been asserted, we report below a short logical scheme:

1. Import the necessary (for an urban representation) geometrical information from an external database;
2. Geometrically identify every building (e.g. determining the centre of every area);
3. Define a contextual space around every building (e.g. a circumference of a given radius);
4. Find the interference between points of geometrical identification (in this case, the count of all points included in the area of every circumference);
5. Draw the survey diagram (e.g. a square grid);
6. Sum all the value determined at the step n. 4 (expression of a density);
7. Define a connections’ domain through a mathematical filter and identify potential incoherent values;
8. Redefine the domain in relation to the survey area;
9. Represent with a legend every value associated with a cell.

The key for the pursuit of the strategy is contained in the 4th point. As a matter of fact, every contextual space contains a different number of objects. In close
proximity to the historical part of the city there is a greater number of elements than in recent built area, independently from the built volume. From this observation, we can have a cartographic representation (see Figure 5) capable of expressing qualitative environmental values, like urban density.

The last consideration suggests the development of an analysis based on a proximity logic. It is the case of the strategy: network of potential relationships (see Figure 6). This strategy represents the network of buildings’ potential relationships, that is to say the maximum number of connections that can be achieved between people living among two neighbouring buildings. For the pursuit of this scope we used the first four points of the previous strategy and, only at last, the fifth. In this way it is possible to formulate a variation of the scheme whose aim is to connect all nodes belonging to the same cluster. At the current state, this system of relations is purely theoretical, since it does not consider the roads and their directions. However, in the diagram it can be noted the difference between the residential and the industrial parts of the city.

Having put into a relation all the phenomena presented in the previous strategies (see Figures 4, 5 and 6), it is now possible to identify a further strategy which can describe the probability of a relationship. These terms can identify an urban quality and a possible concept design, deriving its value from the volume of buildings, their position and the network showing the potential connections between them.

A relational value-quality can so be defined in geometrical terms until a prefiguration of a formal model. If we suppose a certain volume per person and if we compare it with the total volume of a building, it is possible to evaluate the potential number of people
living in the considered area. Then, if we consider a population's distribution proportional to the network of potential relationships and if we group it in sets governed by a spatial proximity's variable, it is possible to define the strategy expressed in Figure 7. It shows a scenario, representing the probability that two or more people can be in the same place and get in touch with each other. The map can so describe the attractiveness of a place, giving the possibility to identify a forecasting strategy.

If we summarize the whole itinerary, we can identify three different levels:

1. The first corresponds to the simple visualisation of all gathered data, and it is the more intuitive level that can be expressed through other tools (e.g. GIS as seen in Figure 3).
2. The second characterizes the analysis and processing of the information, relating multiple strategies to each other (see Figures 4, 5 and 6).
3. The third level is the most design related, since it involves the creation of a series of possible scenario or master plan. The model processing is not simple and not automatic, since it involves the description of different behaviours and the interaction of complex systems, material and immaterial. It needs a synthesis, guided also by subjective choices, like the ones that are the basis of a project.

Here below we show some strategies developed by the students of the Architectural Design course held by prof. A. Pizzigoni at the University of Bergamo. Strategy developed by Andrea Mazzoleni and Matteo Rigamonti (see Figure 7). This strategy deals with the vehicular traffic of the city of Bergamo. The diagram highlights the most critical hours and their related air and noise pollution. The strategy is organised as follows:

1. Import urban geometrical data from external databases;
2. Geometrical identification of the roads on the map;
3. Import of town traffic from an external file of the municipality of Bergamo;
4. Associate roads with their relative traffic;
5. Define a three-dimensional mesh depending on the traffic flow;
6. Define a series of isolines on the map;
7. Represent the obtained values using a chromatic scale on the map.

Strategy developed by Marta Caltran and Luciana Melillo (see Figures 8 and 9). This strategy is about the temporal analysis of soft mobility along the Morla river. The adopted parameters are: time, distance and speed (by walking or by bicycle). This strategy ends with the proposal of a new cableway along the same river:

1. Import urban geometrical data from external databases;
2. Compare current data about greenways located in the area with the ones planned by the city of Bergamo;
Figure 9
Soft mobility and new cableway design, 2nd part

<table>
<thead>
<tr>
<th>Destination</th>
<th>Time (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport</td>
<td>1.85</td>
</tr>
<tr>
<td>Fair</td>
<td>1.48</td>
</tr>
<tr>
<td>Station</td>
<td>1.34</td>
</tr>
<tr>
<td>Palanoida</td>
<td>1.23</td>
</tr>
<tr>
<td>Stadium</td>
<td>27.82</td>
</tr>
<tr>
<td>Fair</td>
<td>24.67</td>
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<tr>
<td>Station</td>
<td>20.08</td>
</tr>
<tr>
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<td>18.50</td>
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<tr>
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<td>Station</td>
<td>4.82</td>
</tr>
<tr>
<td>Palanoida</td>
<td>4.44</td>
</tr>
</tbody>
</table>

Maximal daily flows of the main attractors:
- Air: 1,526
- Train: 11,200
- Bus: 28,611
- Car: 2,250
- Bicycle: 21,300
- Pedestrian: 30,555

Distance (km) vs. Time (min) for different mobility types:

- Bicycle: 0.6
- Bus: 3.5
- Train: 4.17
- Car: 3.6

Moovement types:
- Bicycle
- Bus
- Train
- Car
- Pedestrian

Comparison of travel times for different mobility types:
3. Locate the intersections of the designed cableway with the current greenway of the territory;
4. Select the best intersections for tourism and cultural scope;
5. Evaluate travel time starting from the previous selected points;
6. Prepare a diagram based on a 10 minutes travel time for different transport systems;
7. Define a possible route by cableway nearby the Morla river’s path;
8. Calculate new distances depending on various transport systems based on an acceptable 10 minutes travel time;
9. Graphically represent the distances found on step n. 8 for cyclists and pedestrians;
10. Calculate travel time for the new designed area depending on various transport systems;
11. Assess the most important traffic flows depending on the main buildings of the city of Bergamo;
12. Foresee a “maximum flow” scenario with a total of 95,442 people per day;
13. Evaluate travel time by non-sustainable transport systems (cars, etc.);
14. Compare non-sustainable and sustainable travel time to go from a stop to the next one of the new cablewy;
15. Analysis report.

Strategy developed by Giuseppe Traettino and Roberto Lo Giudice (see Figure 10). This strategy analyses the noise pollution nearby the Morla river, showing the influence of the river itself on Bergamo district. Noise level is represented from green (low noise levels) to red (high noise levels).

1. Choose adequate layers for noisy area representation;
2. Assign weight to layers depending on their influence on the territory;
3. Create and overlap the area of influence obtained by layers evaluation;
4. Assess the influence of the river on the noise levels (the entombed parts do not provide any improvement);
5. Create the final diagram.

CONCLUSIONS
This work shows new operative and design possibilities for Landscape Urbanism that, although at a beginning state, have a great potential. The post-urban space can be represented through a dynamic cartography, capable of describing time and motion. Nowadays, free and easier access to data, together with powerful processing tools, enables the possibility to go beyond a conventional cartographic document, which has been treated until now just as abstract analytical object. A digital parametric tool can be fundamental during the design process, maximising the efficiencies and optimising the forms, thanks to the ca-
pability of instantly showing the results related to different scenario depending on the weight of the various selected variables.

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