Interactive Urban Parametric Design

Dynamic generation of alternatives for planning complex urban environments

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Abstract. This paper presents the use of a City Information Modeling (CIM) platform composed of a GIS platform, a SQL database, a CAD design interface and a VPI used to develop the parametric models of possible development scenarios. It calculates urban indicators and measurable design properties in order to better understand and support choices while making design decisions. Such approach improves the generation of alternative scenarios projections supported by the calculation of urban properties.

Keywords. Flexible planning; parametric urban design; alternative scenarios.

INTRODUCTION

The main substantial difference between science and design is that the former aims at understanding phenomena in our environment while the latter aims at transforming and desirably improve the environment. Science plays a fundamental role in the way we design as it provides deeper awareness on the phenomena constraining and affecting our designs. As phenomena in our environment, and in particular in our urban context, becomes more complex, a growing need for in depth knowledge on such phenomena becomes evidently mandatory for enabling efficient and effective solutions for urban design problems.

The use of parametric tools in urban planning should produce more than just a stylistic design; instead they should assist the designer through the negotiation between land compatibility issues and scenario projection. Integrated analysis and design tools structured as City Information Modeling (CIM) systems (Beirão and Arrobas, 2012) deliver a flexible approach to the generation of urban plans, enhancing the capacity of better understanding the complexity that structures these processes. A CIM is composed of a geographic database (DB), a geographic information system (GIS), a NURBS CAD software and a visual programming interface (VPI) including a calculation module for the calculus of urban indicators. The formulation of the planning problem should be presented in a way that uncertainty is relativized through the projection of several possible evolution scenarios, providing means to interactively explore variations on alternative layouts. A CIM platform allows dynamic real-time projections of formal solutions and analytic data, linked to the manipulation of variable parameters calculating density indicators and computing other attributes, such as physical, social and economic data.
DESIGN CONTEXT
The present document reports on the results of a master thesis, on the subject of: alternative scenarios projection supported by the calculation of urban properties. The following methodology is proposed as a resource for better dealing with complexity and uncertainty issues in the formulation of urban plans.

The design problem which has been the study object of this research focuses its attention on the redevelopment of an agricultural dependent settlement which evolved through the last century into an industrial area, too dependent on the extraction and transformation of raw stone. With the recent increasing decline of the activity a new strategy needs to be implemented, adopting a sustainable and preventive territorial model. This intervention is seen as an opportunity to stimulate the economy at a regional level, as it should be able to attract local and external investment, while creating new jobs.

The intervention site contains a set of three similar small settlements each with a strong centre with typically rural morpho-typological characteristics. The outskirts of the settlements present a dispersed industrial tissue that emerged on a previously rural based frame. The three settlements are close (7km) to a small historical town, Sintra, classified by UNESCO as world patrimony thirty kilometers away from Lisbon, Portugal. The area is well served in terms of transportation by a highway and a train line coming from Lisbon.

The challenge is to find alternative scenarios for a shrinking context on a dispersed territory by trying to invert this tendency using the existing local potential and evaluating the properties of those scenarios. The research was developed with the support of the city council in charge of the area presented in Figure 1.

Some sub-problems were identified at this point, regarding:
- The land-use structure: unadjusted territorial model urging for a functional reinterpretation towards a more flexible classification.
  - The street network: excessive network length shaped along a labyrinth path structure; insufficient and disqualified pedestrian corridors; the current traffic structure induces industrial heavy traffic to cross the small town centers;
  - The Industrial settlement: stone quarries and stone transformation industries tend to generate extensive areas of under qualified exterior areas creating an unpleasant urban landscape; many industrial buildings and extraction quarries are abandoned leaving large areas absent of human activity; small urban blocks in town centers are suddenly cut by large industrial plots sometimes spreading over more than 500 meters without any connection with other urban areas; decentralized infrastructure.
  - Population statistics: last censuses reveal a loss of population, mostly related to the incapacity of stimulating jobs growth; population excessively aged.
In short, this is the situation from where we start.

**Research question and assumptions**

The main research question is: what are the least transformations that we need to apply (or stimulate) to keep the area active and sustainable?

To simplify the usual too broad use of the concept of sustainability, we will essentially focus on trying to find the least transformations (i.e., the least investment effort) necessary to produce the best possible economic activity considering that a good city structure is mixed use, provides encounter, interactivity, and pleasant dwelling areas. It is also assumed that compactness, public space (or street) continuity and good connectivity are essential factors for the development of successful urban environments. Such assumptions follow principles already available in current literature such as (Barton et al., 2003; Marshall, 2005; Knox and Mayer, 2009; Carmona, 2003; Steiner and Butler, 2007; Duany and Plater-Zyberk, 2005).

**Vision and premises**

There should be a global guiding development vision for this area defining what kind of city we want to produce. Such vision is based on the literature mentioned in the previous section. In practical terms, it foresees the transformation of the main industry core catalyzing multiple land uses whilst enhancing the existing potentials in the region.

**Design premises**

1. land uses and activities need to be reconverted, including requalification of the industrial fabric;
2. infrastructure use needs to be maximized;
3. valorization of the existing public space is needed by recurring to widely accepted or historically proven urbanity patterns.

**Design strategy (goals)**

1. Develop a more flexible land use structure by reconverting the existing functional structures such as abandoned houses, factory pavilions, expectant parcels, and so on. This strategy should provide:
   - new uses to the expectant spaces;
   - the valorization of the contiguous areas;
   - the preservation of its initial conditions, allowing new interventions to be considered whenever needed.
   - the progressive adaptation of the agricultural and industrial activities;

2. Considering the excessive network infrastructure there should be applied transformations that are capable of maximizing the network use. It should not be necessary to extend the network except for providing room to redefine street hierarchies, break some of the great obstructions found in the area (islands with a perimeter over 500 meters) or create a catalyzer effect. Even in such exceptions design should seek the smallest possible extension.

3. The reorganization of the public/private space networks relation is possible by changing some urban properties such as: legibility, continuity, scale of context, and improving the quality of the physical space.

**Design criteria**

To verify the achievement of the above enounced goals, some criteria were established for evaluating the shift of the existing conditions towards such goals. Their function is to measure and evaluate the following properties:

- improvement in compactness;

  Compactness may be read through a relation between land coverage (GSI - Ground Space Index), building intensity (FSI - Floor Space Index) and island size measured at island level. These concepts follow the Spacematrix definitions (Berghauser-Pont and Haupt, 2010). Compactness has two sub-properties: it rises as coverage rises to the value of 1 and gets intensified as FSI rises above 1. Note that, the property of being compact is essentially determined by GSI being close to the value of 1 and that FSI can only be used to compare the intensity of the land use. The FSI value of 1 defines the turning point from which
obtaining open space implies staking construction, hence the intensification sub-property.

Island size (surface) is also important to consider because from a certain size above, access to sunlight (or simply access to buildings) implies the existence of some open space. To make things a bit more complicated the need for sunlight access is also dependent on the type of use of the building, housing being perhaps the most demanding in that regard. There is therefore a relation between the average building footprint ($F_i$) and its needs regarding light access and henceforth regarding OSR (spaciousness). For highly compact islands the smaller the average building footprint the higher the demand for spaciousness following the principle that there should be more points of access to sunlight or more open space. The average building footprint gives also some information about the predominant building types within the island (Chaszar and Beirão, 2013).

Therefore, at island level we calculate island area ($A_i$), island perimeter ($P_i$), average building footprint ($F_i$), FSI, GSI and OSR. The combination of these properties shall be subject to interpretation to give support for design decision by following the above stated conventions.

- improvement in connectivity;
- maximization of network usage or efficiency;

This maximization cannot be measured by network density but rather by a relation between building intensity and the network length, in other words, GFA divided by the network length. The obtained measure is expressed in the unit m²/m. This measure is meaningful if calculated at district level. This indicator shall be called network load ($N_l$).

The above properties are measured against the following factors arising from hypothetical design transformations:

- amount of new construction needed (the less the better);
- amount of existing construction rehabilitated and reused (ideally, all abandoned buildings should be revitalized but preferably by private investment due to some catalyzer effect stemming from the first step of the intervention);
- amount of new streets created (the less the better, although maybe needed for connectivity improvement in areas cut by large islands);

The latter properties are measured by comparing the existing state of the context (properties of the context) and a state after a design transformation (properties of a scenario).

**METHODOLOGY**

The design process followed a strict methodological approach comparing alternative development scenarios. The study is built on a CIM platform. As it was previously referred, the CIM platform contains a design interface defined by a NURBS-CAD software and a visual programming interface (VPI). Figure 2 describes the design workflow.
In our model, we used Rhinoceros as the CAD platform and Grasshopper as the VPI. The model was built from the existing GIS data, statistical data and complemented with a data survey on location with the additional support of Bing Maps using birds-eye view. The data was normalized and stored in a database which was later connected with Quantum GIS and Grasshopper using the Slingshot component. By connecting the database with the VPI the GIS platform becomes in fact redundant as much of the common GIS analysis can be done within the Rhino-Grasshopper interface. Which one is easier to use depends on the specificity of the queries or analyses being done.

**Analytic interpretation**

The first stage of the process was an analysis of the existing conditions. Statistical data was divided in several district areas following the definition of the National Statistics Institute (INE) which is the institution in charge of statistical surveys in Portugal. The first analysis measures the above mentioned properties at district level following the INE district structure.

A classification procedure was developed identifying the existing patterns of use and agglomeration in the urban structure. By comparing the indicators obtained for each district, and considering that some typically correspond to industrial structures while others typically correspond to small rural town structures we could identify the typical measures of the small town areas and distinguish them from the typical measures obtained for the industrial areas. As a reflection regarding the identification of design goals we concluded that we should improve the area towards our vision by transforming the area in such a way that the properties of the industrial areas would shift towards the properties of the small town areas, considering however that the final goal should approximate values but not reach them because keeping some distinction was needed. The difference was seen as a way of keeping different identities.

The main idea was to first understand the existing patterns so that desirable changes could be identified, leading to a second classification procedure which aimed at identifying a desirable and more coherent land use structure. Figure 3 shows the existing FSI, GSI and dwelling intensity at district level of aggregation.

In total, the analysis interpretation followed 4 steps:
1. Land use classification
2. Interpretation of the results
3. Land use reclassification
4. Scenarios definition and intervention areas subdivision.

The latter step sets the initial state for the intervention and constrains the intervention area to the most significant areas, i.e., to those areas which are likely to have the most impact towards our goals with the least need for intervention. The main criterion for identifying these areas was: finding the empty (or emptier) areas in between urban (small town structure) and industrial structure. There will
be considered three different scenarios, all of which consider the occupation of gaps in the urban tissue. First, scenario A fills only gaps within the town centers. The second scenario (B) extends occupation by filling gaps between town centers and industrial areas. The third scenario (C) extends the occupation towards peripheral areas reducing dispersion and discontinuity. The latter extension evolves only in the direction of the other town centers. All the scenarios respect the definition of an urban growth contention boundary. These areas will be the design intervention areas.

**Design process**

We associated the improvement in compactness with growth expressed in terms of a population growth projection which would correspond to our minimum needs in terms of building intensification. For the present study, three different scenarios were proposed based on population growth projection.

For this stage we had to define the transformations that we would associate with the growth projection.

The design process proceeds with the following steps:

1. Definition of scenarios’ premises (transformation rules); scenarios are built on the CIM platform by combining clustered design patterns (Woodbury 2010) programmed to generate urban design operations;
2. Manipulation of parameters controlling the transformations towards the goals defined above; parameters will be used to improve compactness and network load (see parameter definition below).
3. Calculation of scenario properties and indicators, and data interpretation;
4. Dynamic manipulation of solutions for design exploration;
5. Comparative study of normalized data; evaluation based on the urban indicators as mentioned in Design Criteria sub-section (see above);
6. Solution fine-tuning.

**DESIGN EXPLORATION**

In generic terms, to obtain the desired results the design should improve the public space structure by creating new public spaces which will allow reducing the walking distance between public open spaces. Such reduction improves the connectivity between town centers by improving walkability conditions, considering that the distance of 300 meters would be the maximum walking distance between two spaces (Alexander et al., 1977). By setting these areas we improve the amount of public space at district level. Nevertheless, to achieve the main goals of improving compactness and network load we need to intensify the use of the islands (raise FSI). However, such increment should be the least possible because it means the least investment needed.

**Generation rules**

Therefore we defined the transformation rules needed to increment density considering that such increment will improve compactness and network load.

We used the following rules:

1. Occupation of interstitial areas with flexible use construction;
2. Progressive occupation of non-built areas with a rule constraining the occupation to the formation of small urban blocks.
3. When geometric freedom is available for land occupation an average building footprint will be used based on the calculation of the existing average building footprint, to generate the geometric features of new buildings to be implemented.

**Defining the parametric models**

In the next step we built up the parametric models for the three scenario areas. Each scenario includes an intervention area close to the small town centers following the previously mentioned principles. The application of the transformation rules is applied to each scenario simultaneously on the three areas.

To allow the comparison of the different scenarios a set of indicator calculations are defined in the model. For each scenario we calculate:
1. Indicators before the transformations
   - At island level: island area \((A_i)\), island perimeter \((P_i)\), average building footprint \((F_i)\), FSI, GSI and OSR.
   - At district level: FSI, GSI and network load \((N_i)\)
   - Because districts here correspond to the parcels defined by INE, we also calculated the same indicators for the aggregation of all districts in each small town including the extension areas defined for the largest scenario. In order to facilitate communication we will call this level of aggregation, town level. The comparison of indicators before and after the transformations, calculated at town level will give a comparable set of measures for objective comparative evaluation.
   - Finally, we also calculate network load at regional level considering regional level as the overall study area.

2. Indicators after the transformations
   - At island level: island area \((A_i)\), island perimeter \((P_i)\), average building footprint \((F_i)\), FSI, GSI and OSR.
   - At district level: FSI, GSI and network load \((N_i)\)
   - At town level: FSI, GSI and network load \((N_i)\)
   - At regional level: network load \((N_i)\)
   - Amount of transformations: growth in GFA (gross floor area); growth in network length; total amount of recovered buildings (expectant buildings transformed and occupied with new uses) expressed in growth in GFA.

The parametric models are set in such a way that we have an input parameter raising building intensity in each scenario till a maximum intensity defined by the highest average number of floors found in the existing districts. In this manner we study the possibility of raising the building intensity in the area to highest value sampled in the area. This value was sampled in the analysis at the beginning of the design process.

**Comparing models by comparing indicators**

Having set the calculations procedures in the models, we store the indicators for each scenario pushing it to two levels of intensity: full coverage; and full coverage intensified to the maximum intensity as defined above.

Figure 4 shows the calculation of such parameters for scenario A.

We can clearly see a rise in the values of GSI in the corresponding districts.

Having always the same structure and calculation methods, all the indicators provide an objective comparable structure. The meaning of the individual changes in indicators follows the assumptions defined in the Design Criteria sub-section. However, the comparative analysis of the results per scenario should still be a topic for discussion.

**RESULTS**

Figure 5 shows density distribution manipulation for the three considered scenarios.

The scenario projection tries to capture, from confronting designs with the calculation of indicators, what could be the best design strategies to implement supporting therefore decisions for a final synthesis. However objective the calculation of indicators may be, there are other components of design concepts that may influence the success of a particular scenario. Such aspects were assessed following more empirical procedures by checking a list of gains and threats identified in each scenario.

**DISCUSSION**

In this paper we show a methodology for producing alternative scenarios and the calculation of indicators calculated before and after the transformations applied in each scenario. Urban design decisions are dependent on agreements between many stakeholders involved in the decision process. Discussions are usually based on unilateral viewpoints dependent on the stakeholders’ interests. Many times such
viewpoints are rhetorically twisted in order to manipulate the public opinion, gain support and make their private interests prevail. The present methods can at least provide objective measurable properties on which more objective discussions may be supported. One can argue that, in time, with recurrent use of these tools designers may gain stronger insight relative to the correlation of certain indicators and their observed morphological properties.

In the case of the plan presented here, scenarios and their properties should be subject to discussion, evaluating the meaning of the changes in indicators arising from the proposed transformations against the amount of investment implied in each one. A final option may only arise when an agreement regarding benchmarks and available investment capital is reached by all the involved parties. The proposed method may also be used as a method to study the viability of a phased model by considering scenario evolution.

As an additional improvement to the method, one could take a small set of reference cases taken as good practice examples, measure their properties and then use the obtained indicator values as benchmarks to achieve in design generation.

CONCLUSIONS

As a conclusion, the methodology used in this design process showed strong objectivity in the support of design ideas as design manipulations are accompanied by the calculations of their properties. The methodology showed also to be strongly efficient in dealing with dispersed complex territories where strategies towards the development of stronger urban cohesion and higher compactness are seen as the vision towards a more sustainable urbanity (Portas et al. 2003). Further work can be done to improve information by adding analytical procedures on the topological properties of the network.

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**Figure 5**
GFA, GSI, FSI, N, NL existing and growth indicators for scenarios A, B and C.