

Parametric urban design

An interactive sketching system for shaping neighborhoods

José N. Beirão¹, Pirouz Nourian², Bardia Mashhoodi³

¹TU Delft / TU Lisbon, Netherlands / Portugal, ^{2,3}TU Delft, Netherlands.

¹(<http://www.urbangrammars.com>)

¹J.N.Beirao@tudelft.nl, ²P.NourianGhadikolaee@tudelft.nl, ³B.Mashhoodi@tudelft.nl

Abstract. *In this paper we show the structure of an urban design parametric system. The system is dynamic and builds an interactive relation with the designer updating the layout and related data at each input change. The responsiveness of the system allows the designer to gain awareness on the qualitative consequences of each design move by comparing a design state with a set of urban indicators and density measures which are automatically calculated along with the geometrical updates.*

Keywords. *Parametric urban design, city modelling, urban planning.*

INTRODUCTION

Complexity and uncertainty of urban environment raise doubts about static and solid decisions in field of urban design. Cities, as all other open systems, are complex and self-organizing. The context of a project, as a starting point of urban design, is changing constantly in non-linear way (Portugali, 2000). Moreover, various stakeholders are involved in design and realization of an urban plan. Uncertainty of economic, social, and political atmosphere results in vibrant policies and decisions from stakeholders. Therefore basic inputs of a design process, for instance total size of investment or functions, may change from time to time. However, the interrelations between elements of urban form can be fixed and predefined by designers. Current urban design practices ignore urban 'processes' and 'time'. Urban design almost always presents a fixed blueprint based on a snapshot of a situation. This approach is not capable of fulfilling the necessities of urban regeneration process. Therefore, objective of urban design need to move from static design of

a specific layout toward complex and dynamic design of generic solutions.

It can be argued that experienced designers can do proper judgments on the qualities of a design just by visually assessing partial or incomplete stages of a design but the quality of that judgment can be improved by giving extra information including density indicators and performance measures needed to complement the plan. Typically in urban design, density measures play an important role in the assessment of the plan layout. A correct visual interface should provide such information as part of the visual output. To approach that, we developed an urban design system based on the concept of arranging design moves in the form of parametric design patterns (Woodbury, 2010), programmed in a parametric design software which the designer can use to build up a dynamic design. The design patterns generate urban types which can be applied and manipulated through the available parameters. The suggested types refer to commonly used

composition elements in the field of urban design such as main streets, grid types, main buildings or public spaces. The use of types for designing is argued by several authors as an approach to enhance the quality of designs as they carry the intrinsic qualities embedded in the recognized evidence of commonly used types (Habracken 1988), (Kelbaugh 1996).

Most past and present discussions on the sustainability of urban fabrics concern the pros and cons of compact cities versus sprawl. There is among many researchers and professionals a consensus that compact settlements are more sustainable than sprawl, and that dense cities will somehow halt an unsustainable increase of consumption of transport, energy and resources (Newman and Kenworthy, 2006). Moreover, greater density is considered to be positively associated with the vitality of urban areas. However, denser urban environments do not automatically mean more sustainable and vital urban spaces. It needs to be seen in combination with other factors as accessibility, layout, land use pattern, etc. On the other hand, density measures provide an appropriate platform for parametric urban design due to their relation with the shape of built environment. In this research we explore holistic generic solutions based on density measures, neighborhood layout and mixed-use pattern. Spacematrix method (Berghauser-Pont and Haupt, 2010) provides an adequate platform for parametric abstraction of the urban form in terms of density measures. Results show that basic density measures are adequate to describe the configuration of urban form in various scales in different cities. This method also suggests a set of performance measures such as daylight exposure, accessibility measured by means of network density and parking performance index. However, design exploration is needed to support decision. Being able to sketch a design and continuously getting feedback on the urban indicators is therefore a desired feature in the urban design process. In this paper we show the basic concepts for such a design tool.

PREVIOUS WORK – THE PROBLEM OF DESIGNING NEIGHBORHOODS

One of the most successful algorithmic concepts was the concept of patterns (Alexander et al, 1977) which has been used in many knowledge areas namely in the field of urban design. The main concept proposes that a recurrent occurrence in the (urban) environment may be solved by applying a generic solution whenever such occurrence is detected in a particular context. In other words, it involves a problem recognition and a generic solution for which specific parameters should be provided to obtain an adequate solution. A set of patterns defines a pattern language. Previous work showed that urban design generic patterns can be encoded using generative rules in the form of discursive grammars (Duarte, 2001) to provide formal solutions to particular design moves that urban designers recurrently use in their design practice (Beirão et al, 2011). Discursive grammars provide a rigorous formalism to describe an occurrence in the design context, the specifications for designing a particular design move in the form of description grammars (Stiny, 1981), and the design rules in the form of shape grammars (Stiny and Gips, 1972) to instantiate the design move. Beirão et al (2010) present an implementation in a CAD software (AutoCad) which provides a few sets of toolbars to generate the design moves. They show a set of tools for designing main streets, grid types, public spaces, building types, a set of inputs for program specifications and other tools to manage building height and mixed uses. The urban design model presented in this paper was inspired on this structure but defined on a parametric design platform.

Defining a neighborhood and what a neighborhood should contain is a common and controversial research topic. In the development of our tool we implemented the features that are mostly considered common ground for planning neighborhoods. However, we found some consistencies in specialized literature used to structure the design tool:

- Many authors agree in the interval 5000-10000 people per neighborhood / community as parts of districts with 20000 to 100000 people.
- This size has enough critical mass to have at least a school and a community building, a main street with shops, a central square and a local square.
- The neighborhood has mixed uses, both vertically and horizontally. The degree of mixture raises as it closes the neighborhood centre.
- Block size varies between 1 acre and 1 hectare. However, there are many successful counter examples with bigger blocks (e.g., Berlin, Amsterdam).
- Squares present a wider variation, but still the same range between 1 acre and 1 hectare is acceptable.

(Alexander et al, 1977); (Barton et al, 2003); (Marshall, 2005); (Moughtin, 2003); (Moughtin and Shirley, 2005); (Jacobs, 1961).

Marshall (2005) shows a large survey on urban grid types identified by several authors on their writing on urban morphology (Appendix 4). At least the rectangular, the radial and the irregular (organic) grid patterns seem to be present almost everywhere in urban design literature. We used the two first as our main design drivers. The organic grid pattern should be regarded as an emergent pattern and therefore we did not use it as a designing pattern. However, Marshall refers some characteristics of the common structure of street networks which are usually perceived as pleasant urban environments. Such street structures have short and long routes, a relatively great amount of 'T' junctions, some crossroads and some few cul-de-sacs. To integrate such ideas we added to our set of street grid types a third street pattern which we called the recursive street generator and it is described ahead.

HOW URBAN DESIGNERS DEAL WITH URBAN DESIGN DECISION?

According to Schön (1983) design evolves by a series of incremental reflective moves with a see-move-see structure where the double appearance of 'see' underlines the importance of

reflection on both an existing state and the consecutive transformed state of a design. Lawson defines design as a negotiation between problem and solution through the processes of analysis, synthesis and evaluation (2006). This structure seems also consistent with the one found in the City Induction research project (Duarte et al, forthcoming) where an urban design system is proposed based on three integrated models aimed at formulating, generating and evaluating urban designs. In urban design the structure of design problems is said to contain some determined components (Dorst, 2004) with objective definitions that can be computed and undetermined which are intrinsic to design problems. Density indicators (Berghauser-Pont and Haupt, 2010) fall in such category and can be incorporated in a design tool providing continuous updates on such measures. Our main goal in this research was to keep the reflective features of the design practice in our design tool providing by computational means continuous calculations updating information on determined components of urban design problems at each designer's move. Such a system should enable a designer to have precise information on indicators and properties of the designs being produced and allow him/her to manipulate common urban design inputs to control the design outputs.

THE DESIGN PROCESS ON A PARAMETRIC PLATFORM – THE WORKFLOW

According to the previous considerations, an urban design system should be able to:

- be applicable in every design context for any district size and be able to apply different kinds of design programs;
- be interactive and responsive providing good visualization output both in terms of design layout and associated analytical data (indicators, attributes, indexes, etc);
- be able to implement and design the main features that compose a neighborhood.

Considering these aspects we implemented a parametric urban design system using a NURBS-CAD environment using a parametric programming interface. The CAD environment used in this work was Rhinoceros® and the programming interface was Grasshopper®. The system aims at designing urban plans at the neighborhood level or district level to use Berghauser-Pont and Haupt's terminology (2010, page 103).

A particular kind of urban design workflow was considered starting from a specific set of inputs for which a specific set of outputs is produced. Figure 1 shows the phase model describing the generic workflow. There are two types of inputs – geometrical inputs and data inputs. In Figure 2 we can see the set of geometrical inputs which is divided in 4 types: site (defined by polygons); composition elements which are subdivided into main streets (defined by lines and curves) and focal points representing the location of the neighborhood centre, local squares, public buildings and city objects in general; a vertical parameter defines the maximum number of floors; and a set of grid types (rectangular, radial and recursive). Each of these inputs has a set of associated parameter inputs. For instance, a main street has as attributed street width.

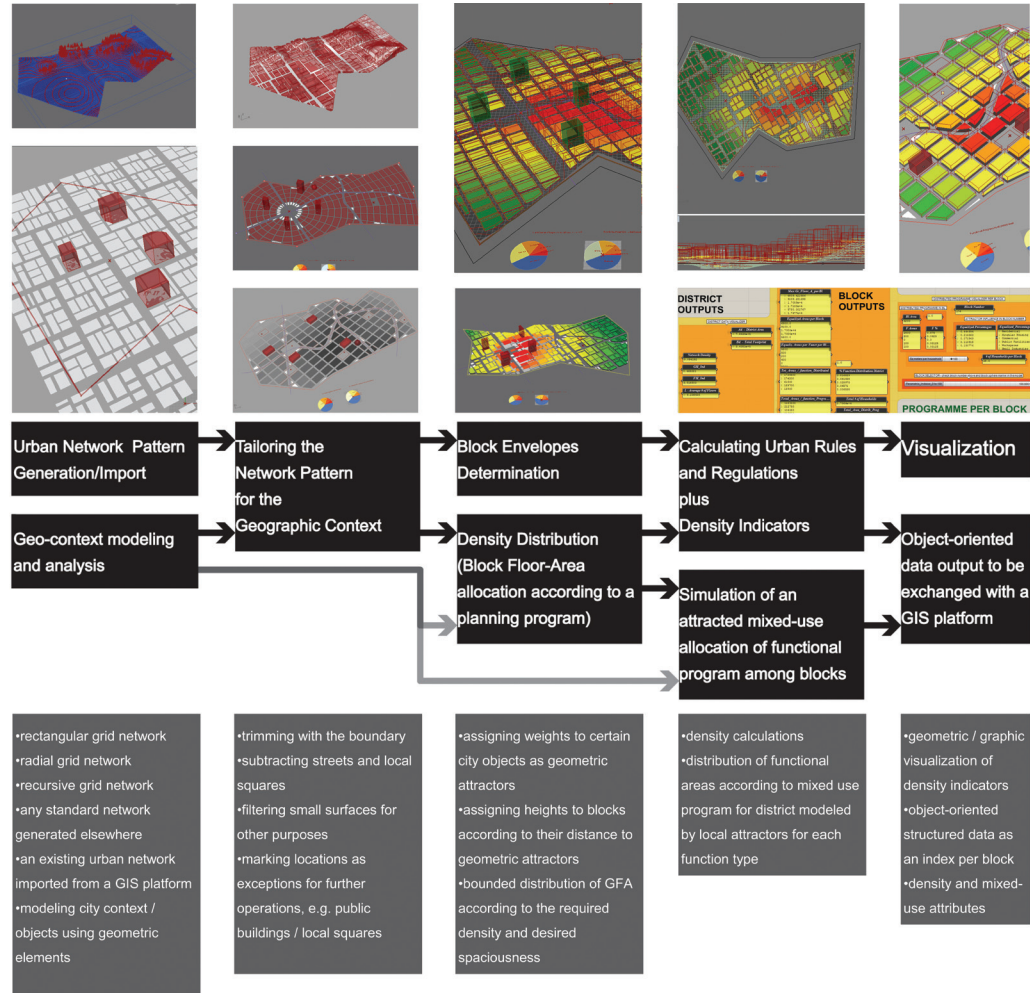
The elements are located anywhere inside the site boundary by the designer and they may be relocated at anytime during the design process simply by dragging them elsewhere or changing them by moving their grip points. A selected grid type (rectangular, radial or recursive) is tailored for the site boundary and the algorithm combines the grids with the other urban elements subtracting them from the main grid geometry. Some inputs refer to options which are defined as switches in the design interface. They allow the designer to choose, for instance, which grid type to apply. The other input parameters allow changing the output appearance of each type.

The data inputs are shown in Figure 3. There are 3 types of data inputs: goal indicators which define the density goals or constraints of the urban

program, option switches and context adjustments which are input parameters regarded as design options that can be manipulated by the designer to fine tune the design. The designer explores the options following the workflow sketched in Figure 1. The designer considers the topography and the contextual conditions of the site, extracts the areas that are considered too steep and eventually identifies zones for which different planning rules or strategies should be applied. This can be a traditional analytical process or enhanced using GIS tools providing the information to set the primary elements of the design. As a final result we obtain a site area subdivided in several zones for which different planning strategies may be applied (see also Figure 2). The site geometry is inserted in the designing environment. The designer defines the position of the main composition elements of the design, namely a focal point and the main streets within the site boundaries. This is drawn directly in the NURBS-CAD drawing environment. Accuracy regarding the composition of elements is not an issue as they may be moved or changed at any time during the design process. Then the designer chooses between three available grid patterns (rectangular, radial and recursive) and explores the available parameters. The selected grid is dynamically updated in the drawing interface. The orientation of the grid is a common parameter that allows the designer to change and fine tune the grid orientation. The recursive street generator designs street grids based on a rectangle dissection rule. The rule applies if the area of the rectangle (block) is bigger than a user predefined area and the block side is constrained to a minimum value corresponding to a user defined number of pixels. The pixel size is also predefined by the designer.

The designer filters several areas in the main model to which exceptional rules or design goals can be assigned. For instance, certain blocks can be set to be small public squares and others to be filled by public buildings. The main process is defined as a filter, a design pattern that isolates particular sets of

Figure 1
Phase model showing the
regular workflow for using
the design tool.



geometric features cut from the main geometry for having specific predefined conditions. The process can be replicated to create sets of geometry to which different generation rules can apply.

The building height is managed by setting the maximum allowed number of floors. The value is used as input for the 3D representation of the maximum allowed building envelope. The number

of floors is defined as a target number which is distributed through the grid as a simulation of land value. To simulate the effect of land value we defined the number of floors in a block as a function of the distance to a set of positive attractors – main square / main streets / the city centre – and a set of negative attractors (repulsion effect) – site boundary. This function changes the number of

floors depending on the resulting calculations. The distribution is determined using bounded distribution methods. The designer controls the intensity of the overall attraction effect using a set of sliders. A similar process is used to distribute the program defined in terms of building intensity and translated into gross floor area (GFA). The indicators are calculated and provided in the interface allowing for immediate empirical evaluation of the output supported with hints provided by studies on morpho-types. The provided indicators follow the conventions of Berghauser-Pont and Haupt (2010). The basic indicators are: FSId – Building Intensity; GSId – Coverage; and ND – Network Density; and OSRd – Spaciousness.

Typically, master plans use as planning devices a density measure expressed in terms of a maximum allowed density (here defined as FSId), a maximum coverage and quite often a maximum allowed height or number of floors (H). In most

situations, to foster design flexibility the values express maximum allowed limits which are set independently of each other. A minimum amount of free public space (minimum allowed OSR) can also be used as a planning device expressing some desired qualities for the public space. Considering the given site area, the existence of a maximum allowed FSId provides the calculation of a maximum allowed gross floor area (GFAd) for the district. The average number of floors L is calculated as an output district level indicator. The system outputs regulations defined at block level in terms maximum number of floors (H), maximum FSId, maximum GSI or minimum OSR. Figure 4 shows all the system's inputs and outputs. The 3D model shows graphic outputs of the indicators for designer visual assessment. Any change applied to the model including filtering blocks to define squares, parks or public buildings will automatically update the regulations in each block.

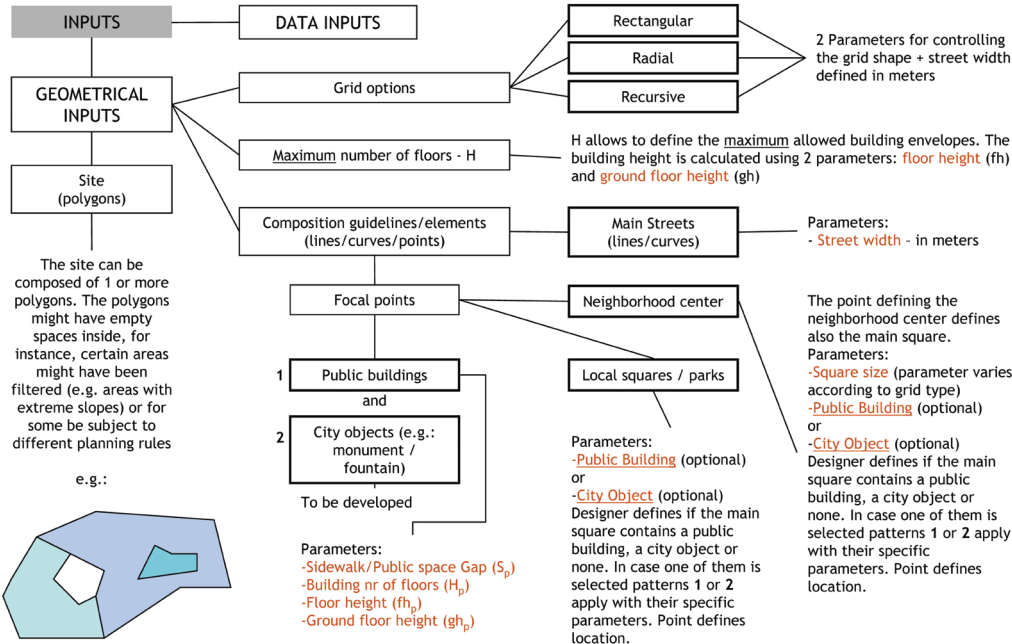


Figure 2
Geometrical inputs.

Land use is addressed in our model as a simulation. It simulates the distribution of uses considering the same urban attractors as before but using an independent interface. The attraction/repulsion effect is set differently for each use considering the land use program in terms of relative percentage of Housing, Commerce, Workspaces, Facilities and Small Industry. The program outputs a distribution of uses per block visually defined with a pie chart and a block indicator.

Figure 3
Data inputs.

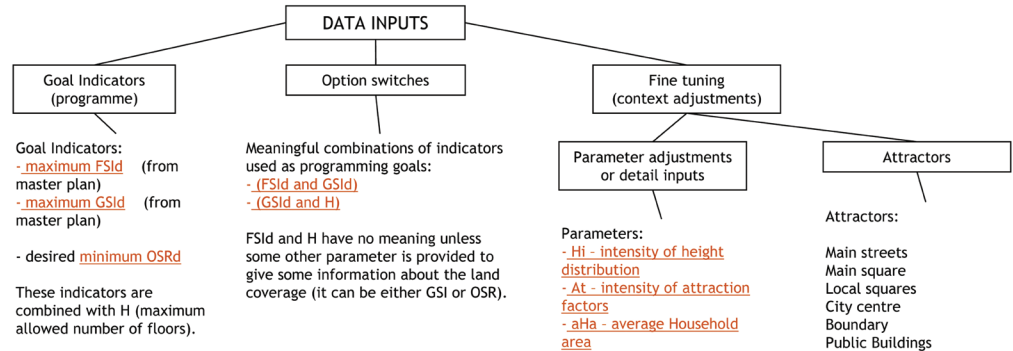


Figure 4
Outputs at district and block level and district level. The shaded indicators are interpreted as defining the base for a regulation or implementation code at block level.

Outputs at block level		Outputs at district level	
Identifier	Unit	L - Network length	M
Block number - index	Integer	Nd - Network density	m / m ²
Attributes / urban indicators		Connectivity Ratio	Crossings per hectare
FSId - building intensity	m ² /m ²	GFA _d - gross floor area (district)	Square meters or hectares
GSId - coverage (block)	m ² /m ²	GSId - coverage (district)	m ² /m ²
GFAI - gross floor area (per block)	Square meters or hectares	Hhd - total number of households	Integer
OSRI - spaciousness (private OSR)	m ² /m ²	Md - total construction mass	m ³
Hhi - number of households in block	Integer	Dd - density as households per hectare	Hh / hectare
Mi - block construction mass	m ³	B - base land area	Square meters or hectares
Li - average height (block)	Number of floors	Ld - average height (district)	Number of floors
max H - maximum height	Number of floors	PPI - parking performance index	If ppi>1 parking capacity is insufficient
AI - block area (extracted from geometry)	Square meters or hectares	DF _s - daylight factor	0-100
Distributed function / use		DPI - daylight performance index	% of floor space exposed to sunlight
Function	String		
Function intensity in block (%)	Percentage		
Area per function	Square meters		
Geographical location			
Centroid of block polygon	Point coordinates		
Polygon corner points	List of point coordinates		

As an added feature, the designer is able to see the urban indicators shown in Figure 4. An immediate relation of the design morphology with the urban indicators is therefore available for designer control and reaction.

DISCUSSION

The design system described in this paper is structured as a very interactive design system providing the most common features for designing neighborhoods. The system allows a parametric manipulation of a design whilst providing density measures about the outputs for a better assessment of the qualities of the proposed design. This assessment was based on commonly used urban indicators. The output is both visual and numerical extending the designer's awareness on consequences of his/her design decisions.

However, the tool still contains several limitations, most of which may be resolved with further work or technology development. The main limitations are:

- Adjusting the standard grid to an existing context connecting the new streets with existing ones. Also connecting two grids in neighboring zones.
- Extending the possibilities of adjusting the design to the topography.
- Environmental issues can be improved even though the designer is able to control the grid orientation and daylight and parking performance indexes are calculated.
- Extending the tool to include property features would be an important upgrade.
- Integration with GIS tools or at least with GIS supported analytical routines.
- However difficult to solve some of these limitations might seem, we should especially stress the positive achievements of the design system:
- The system is able to accommodate typological solutions for neighborhood design which respond to a large amount of urban design problems of this nature.

- The system is very dynamic and interactive allowing for continuous design exploration updating solutions at any input change.
- Every design update is both expressed in terms of visual and numerical output (density measures and derived data) allowing designers (or any decision maker) to become aware of the implications and qualities of a particular solution option.

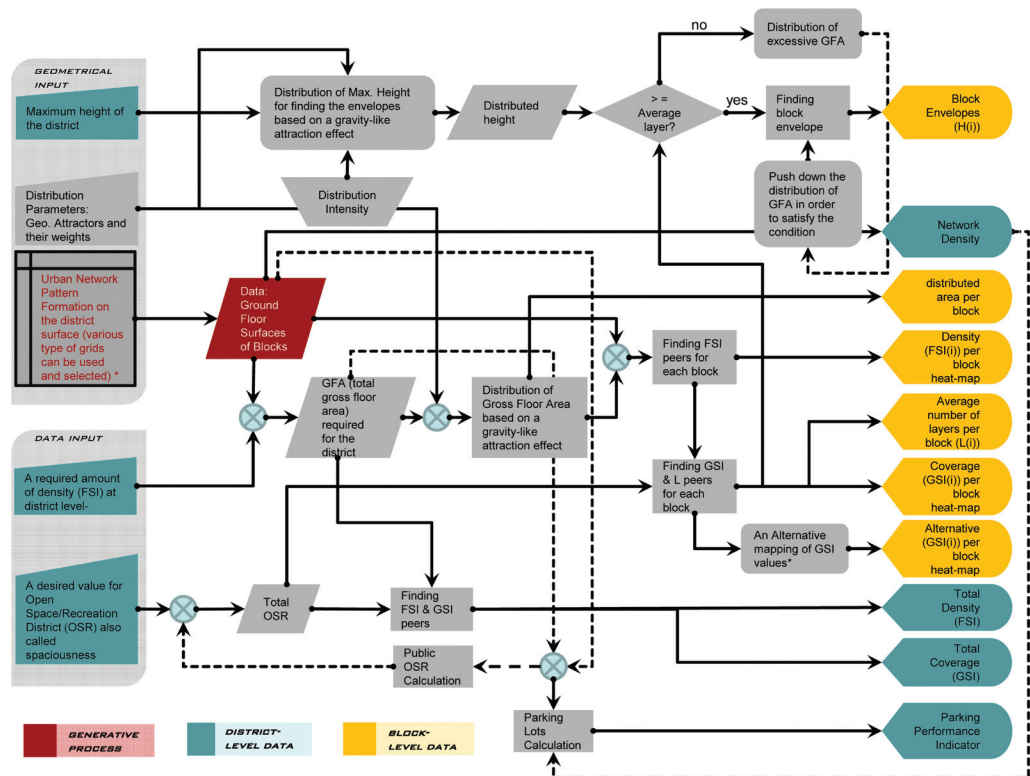
Finally, a route structure analyzer inspired by Marshall's route structure analysis (2005) is being developed to incorporate into the regular design workflow. The analyzer is already operative in the generation of the recursive grid because the generation process builds directly a route structure. However, when the grid is inserted in the main geometry the route structure is subverted and immediately becomes an issue for interpretation. We are developing an algorithm to define a route structure from any generated grid. In order to solve the interpretation problems pointed by Marshall the algorithm was planned to provide optional interpretations which the designer can manually choose by selecting the correct interpretation. However, the algorithm still needs further testing and debugging.

The current approach is focused on internal relationships of neighborhoods. The geographic information of urban context is currently missing. An overwhelming approach to urban design needs to take into account the spatial associations between density and land-use pattern of a neighborhood and its context. In next steps we plan to integrate geo-referenced analytical methods to include contextual information for supporting urban design decision. In addition, effects of proposed design on other urban areas need also to be evaluated as part of whole urban network.

CONCLUSION

In this paper we presented a dynamic urban design system built with parametric programming tools. The main advantage of the presented system is the capacity of continuous change updating associated density measures and derived properties

Figure 5- Flowchart of the urban design tool



or indicators. The measurements are supported on consistent theoretical and mathematical definitions. The provided interactivity is capable of maintaining a dynamic reflective design practice compatible with standard designers' procedures.

ACKNOWLEDGEMENTS

J. Beirão is funded by Fundação para a Ciência e Tecnologia (FCT), Portugal, with grant SFRH/BD/39034/2007. J. Beirão is a member of the City Induction project also funded by FCT, Portugal (PTDC/AUR/64384/2006) and hosted by ICIST at TU Lisbon. We would like to thank Meta Berghauser-Pont, Jorge Gil, José Duarte, Nuno Montenegro, Yiannis Chatzikonstantinou and Bart van Walderveen for their comments and criticism.

REFERENCES

- Alexander, C, Ishikawa, S and Silverstein, M 1977. *A pattern language*, Oxford Univ. Pr.
- Barton, H, Grant, M and Guise, R 2003. *Shaping neighbourhoods: a guide for health, sustainability and vitality*, Routledge.
- Beirão, JN, Duarte, JP and Stouffs, R 2011. Creating Specific Grammars with Generic Grammars: Towards Flexible Urban Design. *Nexus Network Journal*, p.1–39.
- Beirão, J, Mendes, G, Duarte, JP and Stouffs, R 2010. Implementing a Generative Urban Design Model. In *eCAADe 2010 Conference: Future Cities*. p. 265.
- Berghauser-Pont, M and Haupt, P 2010. *Spacematrix. Space, Density and Urban Form*, NAI.

- Dorst, K 2004. *The Problem of Design Problems*. Available at: <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.105.6547> [Accessed 8/6/2011].
- Duarte, JP 2001. Customizing mass housing: a discursive grammar for Siza's Malagueira houses. PhD Dissertation. MIT.
- Duarte, JP, Beirão, J, Gil, J and Montenegro, N forthcoming. City Induction: formulating, generating, and evaluating urban plans. In *Digital Urban Modelling and Simulation. CCIS Series Communications in Computer and Information Science Series*. Springer-Verlag.
- Habraken, NJ 1988. Type as a social agreement. In *Proceedings of the Asian Congress of Architects*, Seoul.
- Jacobs, J 1961. *The death and life of great American cities*, Vintage.
- Kelbaugh, D 1996. Typology - an architecture of limits. *Architectural Theory Review*, 1(2), p.33–52.
- Lawson, B 2006. *How designers think: the design process demystified*, Architectural Pr.
- Marshall, S 2005. *Streets & patterns*, Routledge.
- Moughtin, C 2003. *Urban design: street and square*, Architectural Pr.
- Moughtin, C and Shirley, P 2005. *Urban design: green dimensions*, Architectural Pr.
- Newman, P and Kenworthy, J 2006. Urban design to reduce automobile dependence. *Opolis*, 2(1).
- Portugali, J 2000. *Self-organization and the City*, Springer Verlag.
- Schön, DA 1983. *The reflective practitioner*, Basic books New York.
- Stiny, G 1981. A note on the description of designs. *Environment and Planning B*, 8(3), p.257–267.
- Stiny, G and Gips, J 1972. Shape grammars and the generative specification of painting and sculpture. *Information processing*, 71, p.1460–1465.
- Woodbury, R 2010. *Elements of parametric design*. Routledge.