# Parametric Urban Design

## *Joining morphology and urban indicators in a single interactive model*

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**Abstract.** *A parametric urban design system integrating GIS data in a CAD environment is proposed as a platform for discussing urban plans providing flexibility and information access in an interactive fashion. The proposed system links calculations of urban indicators with the parameter manipulation of the layout geometry, therefore allowing for a systematic update of indicators according to design modifications. Hence, design may be fine-tuned in an informed manner enhancing the quality of design decisions.*
**Keywords.** *Parametric urban design; density studies; design methods.*

### INTRODUCTION

The design of urban plans is based on decisions beyond their morphological characteristics. Moreover, the design of urban plans is also informed and constrained by larger scale plans. In urban plans, density indicators and indices, as well as other co-related parameters are used to bound design within the scope of a target vision. This practice is common in many countries. This is due to the fact that density indicators bound construction expectations within values that although not restrictive in morphology still convey some qualities to the urban space. The issue in consideration is not the discussion of relations between density and urbanity but to consider that urban designers confront their designs with constraining indicators whether they need to do it for following higher level regulation constraints, achieving stakeholder expectations or other theoretical or practical purposes. Furthermore, most stakeholders, including the final users, do not have the experience to understand with enough accuracy the meaning of the values expressed by density indicators. They need to confront alternative solutions and known examples against their indicators to grasp what those numbers might mean in terms of the qualities foreseen for the urban environment (or vice-versa).

In this paper we show a parametric urban design tool that allows the confrontation of alternative designs with indicators. The parametric features of the tool provide a very dynamic design environment where the designer can continuously explore solutions by changing parameters and the primitive input geometries. Whilst adjusting and fine-tuning the design, density indicators are automatically updated.

### RESEARCH CONTEXT AND MAIN CONCEPTS

The research shown in this paper was developed in the context of a wider research project aimed at developing tools for formulating, generating and evaluating urban plans (Duarte et al. 2012). This paper focuses on the generation component showing:

how it can be used to design; how it can respond to a given set of goals; and how it uses and produces density based data that allow qualitative indicators to be determined.

The main concept stems from the principle that urban design decisions may be improved by providing more (and more accurate) information about the design in its context and along the design process. The idea is that changes in form imply changes in analytical results of the evolving design in the context. Considering that design is a reflective practice based on continuous analysis of progressive design moves (Schön, 1987), improving interactivity between the design model and analytical tools will certainly enhance the designers' perception on the consequences of his/her design decisions. Such improvement may allow the establishment of a more adequate framework to support the reflective structure of design workflow and simultaneously improve the information supporting decisions.

The tool imports existing data from a database containing information about a site and its context. The formulation component defines a set of goals to achieve. They can be expressed in terms of density measures to fulfil a description and preferential location of public open spaces and required facilities. On this base, the designer starts defining the composition of the urban plan by organizing a set of primitive elements represented by points, lines (curves) or polygons. The design environment is defined in a parametric design platform in such a way that it can be readjusted at any time during the design process allowing for a refinement of design goals and the design itself. We may consider this an interactive and intuitive process of reflective optimization.

The urban design tool was planned considering the following goals:

1. The tool should be prepared to deal with a regular design process fulfilling the typical designer expectations regarding its usability.
2. The tool should be easily applicable to different design contexts.
3. The tool should provide means to enhance the designers' awareness on the consequences of design decisions and consequently improve the quality of urban plans.
4. The tool should be able to use interactively all existing supporting data during the design workflow, meaning that the tool should be able to deal both with data and geometry manipulation.
5. The tool should be able to provide design alternatives including measures or indicators that may inform an objective comparison between solutions.

The tool was developed on a NURBS CAD design environment (Rhinoceros) and programmed using a visual parametric programming interface (Grasshopper). This environment defines a design with many available parameters that can be changed to produce variations in a predefined geometrical structure. In a way, every generated plan is unique with a unique code. Variations are obtained through the manipulation of parameters and changes made to the geometrical model. In this design environment every urban plan is the result of a particular arrangement between a set of geometric primitives and a particular set of variable parameters.

Considering that we can find operations in urban design which are frequently used by practitioners, such operations can be encoded into modular and reusable algorithms. These algorithms performing recurrent urban design operations can be called *design patterns* (Gamma et al. 1995), (Woodbury 2010) specialized in urban design. They have a reasonably high level of abstraction and a common meaning that designers refer to when describing their designs. Sometimes the professional community has even agreed to use specific names for such typical design moves. Placing a landmark building at the top of a main street or defining a main axis connecting two landmarks, for instance, are common concepts among urban designers.

The tool presented in this paper uses such urban *design patterns* developed as parametric design components to build up its flexibility. The idea is to use modular codes replicating typical urban design actions and build up complex designs combining

and arranging the codes according to the needs of the design context. In other words, the Grasshopper code is structured into modular pieces of code with a particular meaning in terms of urban design which are repeated and combined according to the context.

## THEORETICAL BACKGROUND

The *design patterns* used in the implementation of the parametric design model shown in the next section were adapted from the previous research developed in the context of the City Induction project (Duarte et al., 2012). This adaptation follows a translation of grammar based *design patterns* called urban induction patterns (Beirão et al., 2011) to parametric urban *design patterns*. Urban induction patterns (UIPs) are generative urban design patterns based on parallel discursive grammars (Duarte, 2005). The details about UIPs can be read on (Beirão et al., 2011) and (Beirão et al., forthcoming). The authors identify six sets of thematic UIPs that complete an urban plan. The six themes are: (A) the creation of composition guidelines like main axes, landmarks and other kinds of initial composition elements; (B) the creation of urban grids such as rectangular, regular or radial grids; (C) transformations in the grid network; (D) the creation of public space like different types of squares and plazas; (E) the generation of urban units such as neighbourhoods, blocks or building clusters; and (F) others like the management of land use distribution, building intensity or simple details like street design and urban policies regarding material finishes. Within these thematic sets several UIPs have been developed following a discursive grammar structure such as the latter mentioned papers. A reasonably accurate implementation of that structure was previously implemented in AutoCAD (Beirão et al., 2010) using the VBA and VLisp application programming interfaces (API) but the implementation proved to be slower and less interactive than initially desired. This was the main reason why an adaptation of the same structure was later started using the NURBS CAD + Visual Programming environment. The first steps of this implementation are shown in (Beirão, Nourian & Mashhoodi, 2011) and (Beirão, Nourian and van Walderveen, 2011).

## FROM GRAMMAR BASED DESIGN PATTERNS TO PARAMETRIC DESIGN PATTERNS

In the translation of grammars based design patterns to parametric design patterns the components of the grammar are adapted to a parametric format. In detail, a formal parametric grammar contains an initial shape, a set of shapes, a set of symbols and a set of transformation rules (Stiny, 1980). In a parametric shape rule schema $\alpha \rightarrow \beta$ a specific values can be attributed to all the variables defined in $\alpha$ and $\beta$. For instance, in a particular urban grammar and for specific conceptual reasons a designer may bound the width of main streets between 15 and 40 meters. If a rule transforms a composition axis (defined by a line, polyline or curve) into a main street as shown in Figure 1*a*., we can clearly identify the set of elements that we need to turn the rule implementation in to a parametric design pattern, for instance in Grasshopper. These elements are: (1) an initial shape represented by a line, polyline or curve drawn in Rhinoceros design interface and an initial symbol labelling the shape as an axis $a_x$; (2) a set of transformations that transforms the initial shape into the main street surface and the label $a_x$ into a label $m_s$, which identifies the surface as a main street; (3) and the variable *w* (street width) which varies between 15 and 40 meters and is defined in Grasshopper with a slider Figure 1*b*.

Generically speaking, a urban design pattern in Rhinoceros + Grasshopper environment generates a typical and meaningful urban design move and is composed of an initial shape which can be either drawn in the Rhinoceros drawing interface or obtained from any previous design operation, a set of clustered Grasshopper components that transform the initial design into a partial but meaningful urban design, and a set of sliders that allow an input of parameters considered as variables of that specific design move. In principle, any shape that can be drawn

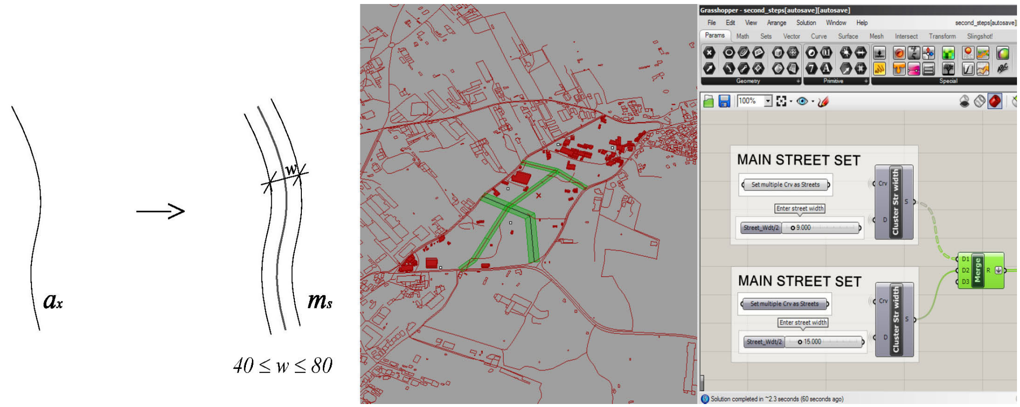



*Figure 1*
*Left: a parametric shape rule transforms a composition axis $a_x$ into a main street $m_s$ with width w.*
*Right: the same transformation using a parametric design pattern.*

in Rhinoceros and read by Grasshopper can be used as an initial shape, but for guaranteeing interoperability with GIS only points, lines, polylines, curves and polygons are considered. To distinguish them from initial shapes in shape grammars, we shall call them design primitives.

## THE DESIGN METHOD AND TOOLS

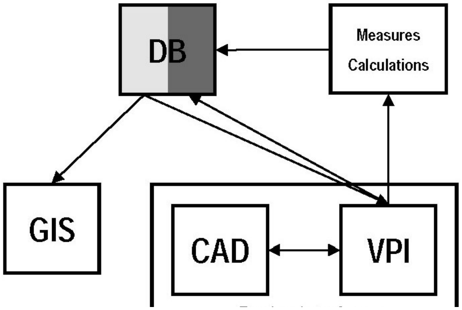
Let us consider that we obtain reliable geographic data about a particular site from a local provider. A regular workflow will comply with the following procedures:

The data is stored in a PostgreSQL database (see Figure 2). The database (DB) can be accessed both by a GIS and a Visual Programming Interface (VPI), in this case Grasshopper. The VPI imports the data using a database query component, Slingshot (http://www.food4rhino.com/project/slingshot), which provides an SQL query interface that enables a selective access to the data stored in the DB. This includes the shape files of pre-existing constructions and thoroughfares as well as an identification of an intervention boundary – the site area represented through its boundary, a polygon. If required, all data can be edited and replaced in the DB. Previews of the existing data can be visualized the design interface by querying data from the DB and connecting them (e.g.: extruding building height from building footprint – Figure 3).

1. The site can be subdivided in many sub-areas represented by smaller polygons. Depending on the design problem and design context these polygons can be defined either by scripting in the VPI or drawing.
2. The main guidelines of the plan or main streets can be drawn in the CAD interface adding curves to the drawing environment using a design pattern such as the one shown in Figure 1*b*.
3. The design process flows by adding design primitives to the CAD drawing environment. Curves can be associated with street parameters – a street width for each street hierarchy (See Figure 1*a*. and Figure 4*a*.). Polygons are associated with an intervention area to which a grid and respective parameters are assigned. Additional geometry may be used to filter areas for different rule attribution or even to define landmark buildings. Points can be used to place exceptional buildings in a grid – public buildings and other facilities – or to locate public open spaces (see Figure 4*b*, *c* and *d*). Points can also be used to filter particular instances in the model to which one may later apply different rules. This functionality allows fine-tuning locally the overall plan adjusting it to very detailed conditions.

4. Equal or separate parameters can be attributed to the design primitives depending on the plan's needs. This can be managed by using one or multiple design patterns taking advantage of modularity of the design pattern concept.
5. The model built in this manner is continuously adaptable due to the parametric structure provided by the design environment. Polygons can be changed by pulling the grip points. The same applies to curves allowing reshaping and relocating streets. And points can also be relocated. The fact is: the design can be always in process.

*Figure 2*
*Design system structure.*



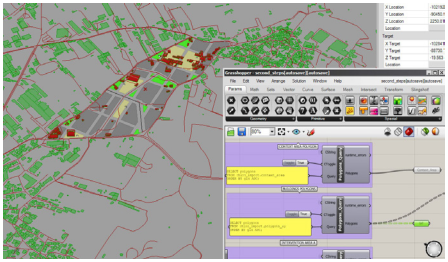

As soon as the geometric model defines construction within an area, the calculation core of the software provides accurate measures of the model. The measures are density based indicators following the calculation model defined in Berghauser-Pont and Haupt (2010). These density indicators are expressed visually in the model using a colour code (see Figure 4*e* and *f*), and numerically in the data interface (Figure 6). The density distribution in a plan can be equal, linear or uneven following a parabolic function that redistributes density according to a set of urban attractors previously defined by the designer. The calculations are updated at each change of the geometrical model allowing for a continuous feedback on design decisions. The density indicators are calculated at district level and block level. Due to the uneven distribution, all blocks can have different densities but managing this diversity is easy because all data is available and editable at any time. Using this information support and the model's geometrical flexibility the designer can continuously fine-tune the design adjusting it to the goals predefined in a pre-design programming phase (Montenegro et al., 2011).

Additionally, following similar premises as for density distribution, the model provides a simulation of a land use programme throughout the plan Figure 5. The designer may interpret the results through the visual and data interfaces and use the results to set regulations for the plan.

All the data generated by the model can then be sent to the database from which other evaluation tools can perform several evaluation routines checking other indicators against predefined reference cases (Gil et al., 2011). These procedures can consolidate a tangible meaning to the proposed solution. However, the evaluation procedures are performed considering a single solution. In any case once the evaluation is concluded the design can be reviewed by further fine tuning the model and adjusting it to new intended goals.

## DISCUSSION ON PARAMETRICISM

Quoting Schumacher (2010): *"Parametricism implies that all architectural elements and complexes are parametrically malleable"*. The approach of this definition is limited to a formal viewpoint; it is simply presented as a matter of style. Schumacher extends the concept to urbanism, coining the term *parametric urbanism* but again simplifies urbanism to a matter of formal style. The concept viewed this way is highly questionable. It could even be reasoned that in urbanism form does not really matter. Some authors support such argument by showing that traditional organic urban tissues, where form emerges as a naturally self-organized order, provide some of the best known and appreciated urban environments (Alexander 1979), (Jacobs 1961), (Barton et al. 2003). More recently, and more accurately pinpointing where the misunderstanding of the term parame-



tricism lies, Mehaffy (2011) calls Schumacher's approach as "*morphogenetic urban design*" and interestingly suggests more objectively valid approaches to the concept by relating how Alexander's patterns (1977) or Duany and Plater-Zyberk's smart codes (2005) may relate to an algorithmic approach to urban design. In this paper we argue that parametric urbanism must involve other kinds of parameters than formal ones and rather integrate dynamically

*Figure 3*
*Data import components and its visualization in the CAD interface. The existing buildings within the study area are using information about the number of floors, also available in the DB, to generate the 3D preview.*

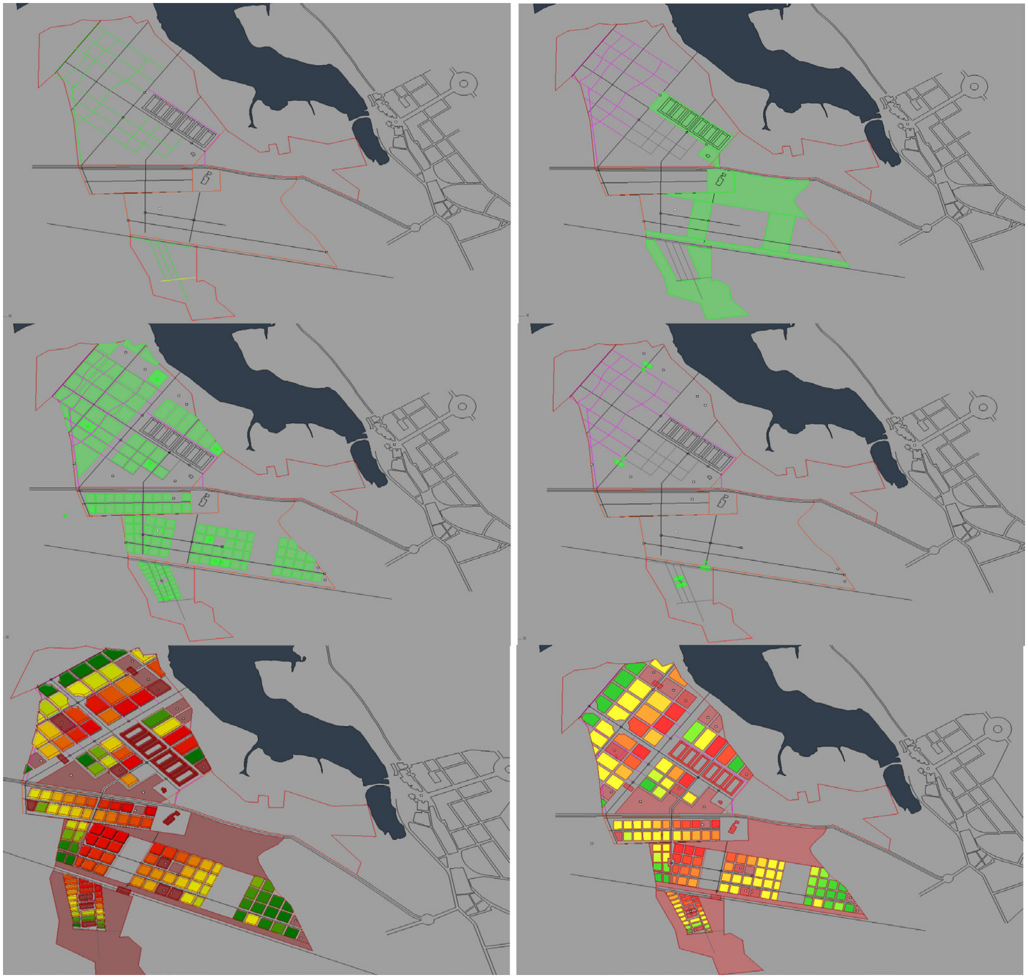
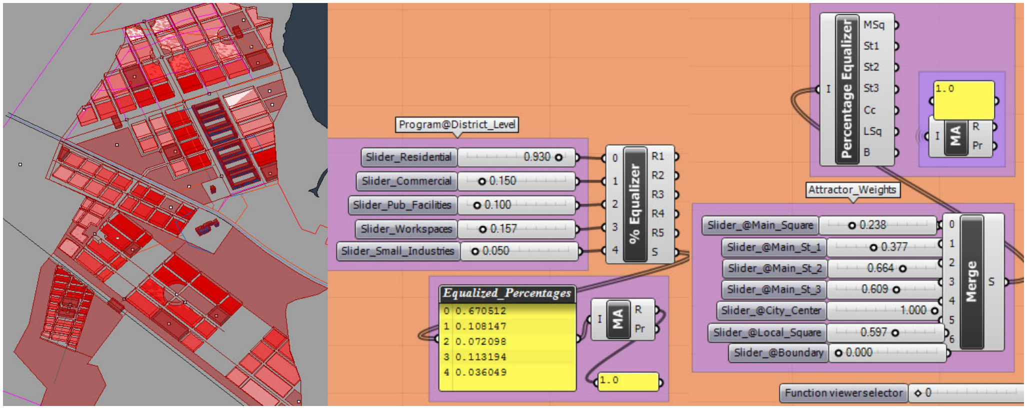


*Figure 4*
*CAD interface. Workflow.*
*(a) existing buildings and guidelines;*
*(b) exception areas;*
*(c) landmark buildings and open spaces; and*
*d) landmark buildings. Density visualization –*
*(e) perspective and*
*(f) plan.*

Figure 5
Distribuition of residential use according to a set of predefined attractor weights.




all available information to support design decision. The goal is not to produce malleable forms, but to relate changes in form with information related with all kinds of urban dynamics. This may be obtained by connecting form, topology and every kind of social data in an interactive design platform where meaningful indicators may be calculated and updated in relation with design trial proposals.

Form may not be the essential aspect of urbanism, however, the practice shows that decision is mainly done based on layout proposals and designs definitely propose territorial transformations that somehow reshape or extend the urban environment. The important issues though, rely on relations between form and other kinds of data, namely on what those transformations mean in terms of densification, connectivity, traffic flows, people's flows, parking needs, as well as other less objective qualities like integration or economical impacts. Decision-making is essentially supported on information gathered on several of these aspects pondering the pros and cons of trial solutions. As in any design process, the design problem formulation is informed from trial solutions as much as from analysis (Lawson, 2006), and therefore an efficient design system should provide ways of assessing an evolving solution rather than simply a final layout. The tools and methods proposed in this paper provide an *intuitive reflective optimization process* which is likely to improve the quality and sustainability of urban design decisions. Furthermore, urban design decision involves many people who have different understanding and different views of the problem; consequently, a dynamic platform where the design model may be easily manipulated and data may be constantly updated can provide a good comprehensive platform on which different stakeholders may reach an objective discussion protocol. Such process may also be considered as more suitable for supporting a democratically acceptable decision process.

## CONCLUSION

Our idea of parametric urban design is concerned with the exploration of urban morphology and simultaneously generated calculations on which decision is supported. Such kind of information allows also that other stakeholders may easily grasp the relations between specific formal approaches and density goals. In the end, the tool provides not only formal solutions, but also a discussion platform upon which a set of stakeholders may discuss urban concepts and support their decisions. From the designer viewpoint it provides continuous fine-tuning in a reflective optimization process.

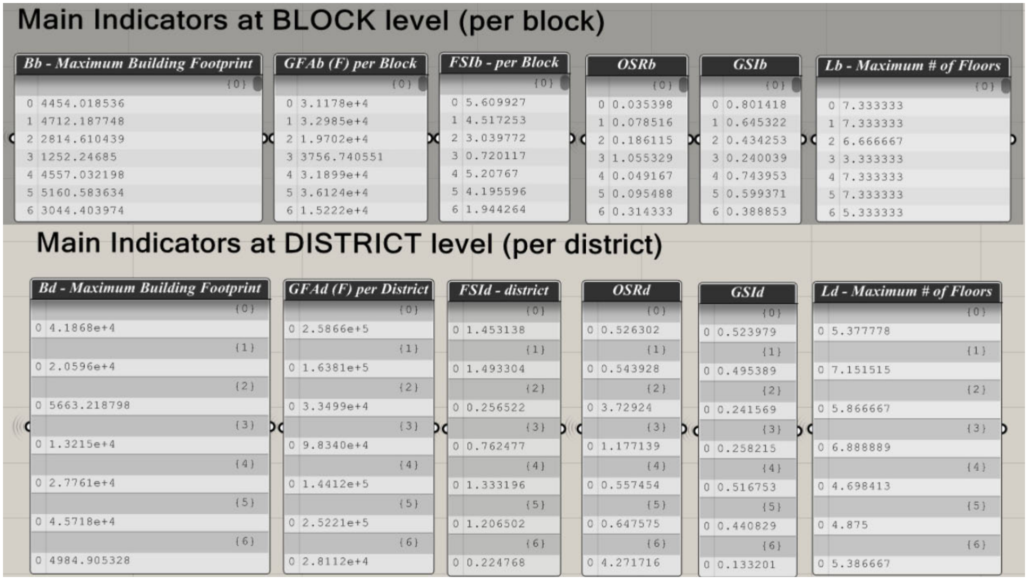



*Figure 6*
*Density indicators at block level and district level (according to Berghauser-Pont and Haupt (2010).*

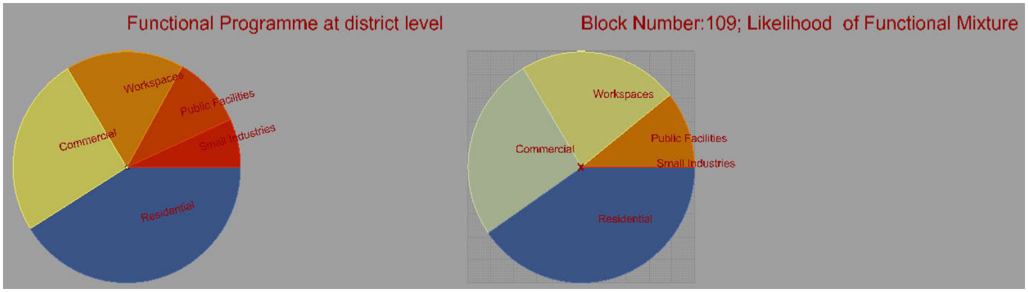



*Figure 7*
*Pie charts indicating the distribution of land use programme at district level and for block number 109. The block information is selected by the designer as needed. A sphere flags the selected block in the CAD interface.*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