Parametric Maps for Performance-Based Urban Design

A lateral method for 3D urban design

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Abstract. *Urban design is a complex process which deals with multitude of aspects to shape quality urban space. On one hand, we have quantitative aspects such as land use, building heights or floor space index which are tackled on top-down approach. On the other hand, we need to take into consideration more subjective, qualitative aspects such as building shapes and space between them based on bottom-up principle.*
In order to connect both principles, a new, performance-based parametric urban design method is proposed. It is based on a concept of parametric maps, which represent spatial distribution of key building parameters (quantitative criteria, top-down) throughout the area and are preliminary loaded into the virtual urban development area. Once parametric maps are loaded, we begin designing a development by placing the buildings (qualitative criteria, bottom-up), which adapt their parameters while changing their locations. Parametric maps thus represent a link between a set of spatial parameters and the actual shape of each building in a way, which connects both, top-down and bottom-up principles of urban design into a single conceptual framework.
In order to evaluate this new method, an interactive prototype application has been developed in Maya (3D modeling software) and the following results were obtained: 1.) a significant speedup is possible in the creation of different design alternatives in early stage of urban design process; 2.) use of parametric maps is most suitable for mid- to large-scale projects (+15 buildings), while they can be redundant for small-scale areas; 3.) possibility of inconsistency with site regulations is diminished.
Keywords. *Parametric; map; performance-based; urban design; urbanism.*

INTRODUCTION

Recent advances in both computer hardware and software have already had a great impact on a way we work today. These tools are very efficient in addressing the quantitative aspects of urban design. Not only they allow for simple analytical calculations, but they also enable extremely complex and computationally intensive research, which was barely imaginable only a few years ago.

Nonetheless, the problem arises when these contemporary tools are to be included into the actual design process. Only then we find out that the computer power is not utilized to its full potential as most of the applications are still based on traditional methodologies. We therefore need to develop new approaches that would take full advantage offered by the power of today's computers. According to

Steinø (2010), parametric methods seem to be the most appropriate to fulfill this task. In the last few years a first generation of parametric urban design applications, such as CityCAD [1] or Modelur [2] already emerged. Although these applications significantly improve the computer aided urban design workflow, they are still merely a highly specialized versions of drawing applications as they do not incorporate any new methodologies.

For this reason various advanced parametric urban design possibilities are being explored. One such attempt is CityInduction project being carried out by Duarte et al. (2012). The concept behind it is to connect GIS and CAD into a common design workflow (Beirão et al., 2012). This way a link between parametric 3D model of an urban area with the data related to it can be established. However, the actual implementation of such a tool is still in early phase of development. When Gil et al. (2010) preliminary assessed the currently available tools, they concluded that there is no single comprehensive platform which suits all needs of the anticipated CityInduction urban design process.

This paper therefore presents a lateral urban design method, one which can extend both, existing and emerging parametric urban design tools.

To better understand a newly proposed method, which is to be used in early, conceptual stages of urban design, two basic contemporary urban design approaches need to be discussed. The compliance to given spatial conditions (quantitative criteria) such as Land Uses or allowable Floor Space Index (FSI) is achieved using top-down principle as this ensures the coherence of individual buildings which form the entire urban tissue. From qualitative perspective quite the opposite is true: the relationships between separate entities (buildings) and spaces connecting them are based on a bottom-up principle. This way the part (building) is in a direct function of the whole, so that it tends towards its cocreation and presents its generic determinant at the same time (Koželj and Capuder, 1990).

Urban design is thus a complex process which takes place between two, apparently contradictory, fields: on one hand there are many objective and measurable parameters and on the other more specific, subjective criteria. Quantitative requirements set out the conditions within which the urban designers need to establish quality relationships between several buildings to form a whole development. Since there is much spatial data involved, it is time-consuming and arduous task to harmonize both quantitative and qualitative aspects of urban design.

Proposed performance-based parametric urban design method is focused on linking both, top-down and bottom-up principles. It is fully adapted to meet the specific requirements of urban design and three-dimensional forming of space at the same time.

The new method is based on usual urban design parameters (e.g. building's built-up area or number of floors) and can thus be easily integrated into the common urban design workflow.

THE METHOD

Overview and principles

In order to tackle the problem of linking both, top-down and bottom-up principles, a semi-automatic parametric approach is employed. This way the input data (parameters) can be separated from the final form of the development (building volumes) which is left to the urban designer.

The connection between both, top-down and bottom-up approaches is established by using *parametric maps* which represent intuitive and straightforward way to define selected parameters for given development. Parametric maps are ordinary bitmap images inserted into digital representation (3D model) of the development area. They *define the distribution of key building parameters across the area* (e.g. building heights - they are high where the image is black and low where the image is white). Once parametric maps are set, user can start placing buildings (of arbitrary shape) into the development area; their volumes are adapted in real-time as they are being moved around the area. A detailed explanation of the mechanism behind this build-

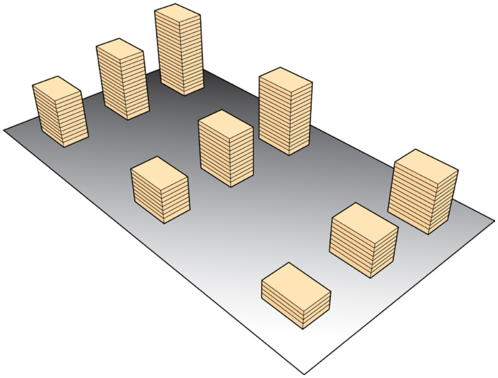

Figure 1
Example of parametric map for number of floors. When buildings are dragged around the area, they adapt its number of floors in real-time.

ing adaptation is given below (see "Parametric maps concept" section).

Parametric maps thus represent *spatialized field of rules* (parameters) which governs each building's parameters according to the location they occupy on site. This way a link between set of rules and the actual shape of the development is established, a link which ensures compliance with any and all parts of the development with the whole.

Based on the proposed method an *interactive prototype application was developed* [3]. This tool allows urban designers to model urban form directly from their goals and check whether they have reached or exceeded given site conditions in real time.

Since parametric maps only define the quantitative requirements, while leaving the choice of actual building form to the urban designer, we can argue they act upon development on a top-down principle. Consequently, the urban designer may devote more attention to the design of a quality relationships between individual buildings during further development process, which is considered to be a bottom-up approach.

Parametric maps concept

The basic concept behind parametric maps is that they embody *spatial distribution of key building parameters throughout the development area*. Using parametric maps, which are ordinary bitmap images projected onto the development area, where the value of each color channel represents arbitrary parameter of the building at specific location, we can spatially distribute different kinds of information about the development, e.g. building heights or built-up area. The application then automatically calculates each building's volume depending on its location (Figure 1).

In this paper a parametric urban design is considered to be a method of forming the development using the desired target values, such as number of floors or gross floor area, which is in contrast with the traditional CAD methods, where the building volumes are defined using external metric dimensions of each building. It is thus possible to define the building volume using relatively simple mathematical calculations, e.g. the building usually defined by the overall dimensions of 20 x 20 x 19 m can also be defined as an 8 floor building with a 400 m^2 built-up area (Figure 2). The advantage of this approach is obvious, since urban designers have more time to explore various possibilities directly within the desired end result.

To clarify further a concrete example is presented in detail. For the sake of clarity we will explain the mechanism on the most basic case: a parametric map which rules the number of building floors (Bf). No building should be higher than 15 (Bf_{max}) floors and no building should be lower than 5 (Bf_{min}) floors:
$Bf_{min} \leq Bf \geq Bf_{max}$

Based on analyses previously carried out, distribution of buildings heights is already known and a corresponding parametric map is created. We decide that the red channel (R) of the image represents number of building floors distribution; or the specific building's number of floors at any given location

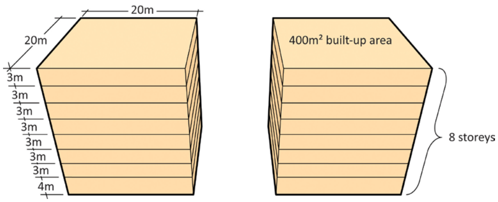

Figure 2
Metric and parametric dimensioning. Buildings are traditionally modeled using standard dimensioning (left), while parametric tools allow for more informative dimensioning using building's end values (right).

($R_{x,y}$):
$0 \le R_{x,y} \ge 255$

Next, the span between minimum (Bf_{min}) and maximum (Bf_{max}) value has to be set, we choose Bf_{min} = 5m and Bf_{max} = 15 m. This way the application is told to remap the R value of 0 to 5(floors) and 255 to 15(floors). Any value between 0 (R_{min}) and 255 (R_{max}) is then recalculated using a simple linear interpolation as follows:

$Bf = Bf_{min} + (Bf_{max} - Bf_{min}) * R_{x,y} / R_{max}$

An example to calculate the building number of floors at the location with R value of 204 follows:

$R_{x,y} = 187; Bf_{min} = 5; Bf_{max} = 15$

$Bf = 5 + (15 – 5) * 204 / 255 = 13$

This way, in the example above, the building at the location with R value of 204 will be 13 floors high. If moved around, it will again recalculate the required number of floors according to R value at given location and adapt the building volume to the

Same logic can also be applied to other parameters that can define the shape of each building, such as built-up area or building heights. If we want to use parametric maps of the secondary parameters, e.g. gross floor area, exact order of calculation must be specified. First the building height should be calculated, as it generates the correct number of floors based on the specified floor heights. If needed, the actual height is adapted so that it matches the sum of floor heights. Only then the application can calculate the correct size of the building built-up area in order to match the desired gross floor area. Nonetheless, all the calculations are simple and fast and can thus be calculated in real-time.

In addition to the shape-oriented parametric maps, other parameters can also be defined in a similar manner, e.g. parametric map of land uses. This way a user has a visual overview of building programs distribution across the area, as the buildings instantly adapt their colors when moved onto another land use. Also, each land use may have different requirements to calculate some of the urban control values (e.g. calculation of required parking lots differs for residential or office buildings).

Arbitrary parametric maps can be defined as long as they do not exclude each other. E.g., it does not make sense to make parametric maps of building heights and number of floors, as they provide the same information, only in a different way.

Implementation

The prototype application is implemented as an extension to Maya (3D modeling and animation package by Autodesk), using its script language MEL (Figure 3). It enables modeling of the development using two approaches. The first way is to let every building automatically adapt its volume to the parameters de-

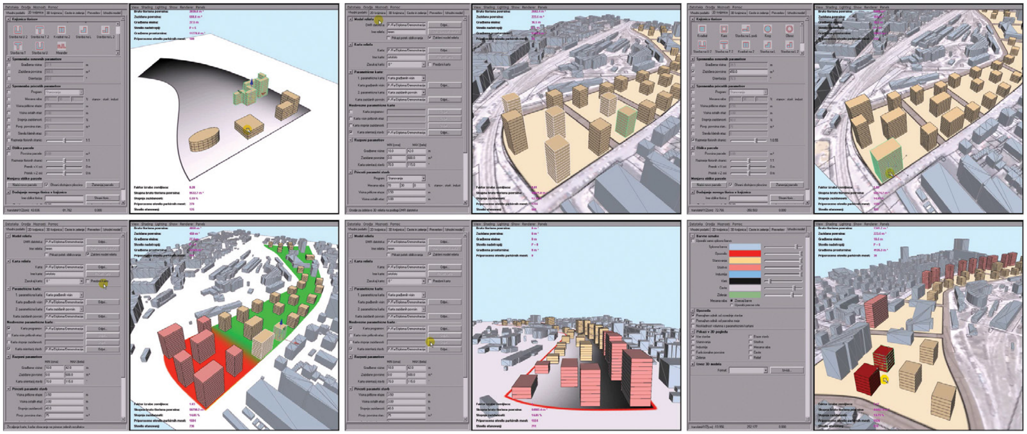

Figure 3
Screenshots from prototype application. Link to the video demonstration, which shows the parametric maps method and the capabilities of the prototype application can be found under references [3].

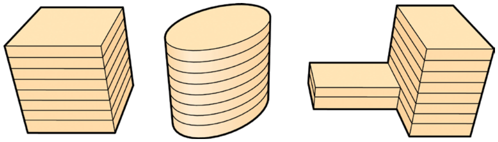

Figure 4
Replacing of buildings. Although of completely different shape, all three buildings in this example indicate the same height and gross floor area; thus one can easily replace another.

fined by parametric maps in accordance with its location. Using this method, a 2D floor plan of the building is inserted into the area and dragged around while building's volume is automatically updated from the parameters defined at that specific location.

The second way is to "overload" chosen building parameters, which allows for flexibility of modeling the development. Once a selected building parameter is overloaded, it is not influenced by its parametric map anymore. Using this kind of parameter overloading, it is important to note that one is consciously moving away from the outlined development as defined by parametric maps.

Any change in the parameters, whether for the whole area or a single building, is reflected immediately. Set of urban control indicators, such as FSI or number of required parking lots is calculated in real-time. This allows for continuous supervision over the entire development and thus promotes performance-based urban design.

As an additional functionality, a prototype tool implements experimental function to raise error warnings when the spacing between the buildings is too small. This happens most often due to insufficient insolation of buildings or when the buildings are closer to each other than the minimum distance allowed.

RESULTS AND DISCUSSION

The major advantage of parametric maps method is in the speed at which it is possible to modify the design of the development. Testing the prototype tool showed that the usefulness of parametric maps increases with the size of the development area.

Prototype tool facilitates verification of different development alternatives as it enables rapid re-placement of buildings into the area within the required criteria. This is an essential component of contemporary urban design practice, worth of special attention.

Since the individual buildings are interchangeable due to their parametric nature (Figure 4), the flexibility of the design, which complies with the planned development strategy, is increased and various alternatives can easily be tested.

The main advantages and possibilities that have been proven when testing the prototype tool are:

- Rapid design of urban development and its alternatives,
- Rapid response to new conditions (automatic changing of development, changing of parametric maps),
- Quick assessment of the development area capacity,
- Real-time calculation and display of urban indicators such as FSI, built-up area, etc.,
- Reduced probability of errors.

Some of the shortcomings of the new method, as implemented in the prototype application, also showed up:

- Preparation of parametric maps can be time-consuming,
- Possibility of false parametric maps or input parameters span which can lead to false design,
- Lack of the tool for direct modeling of the buildings,
- Parametric maps are redundant when creating small scale developments.

CONCLUSION AND FURTHER WORK

The main advantage of using a parametric maps approach over traditional methods is in *the possibility of quick insight into the new situation when changing key parameters*. In other words, change of one of the input parameters can instantly adapt the whole development area. At the same time the possibility of errors is reduced when compared to manual changing of separate buildings.

Urban design with parametric maps allows great time saving when articulating buildings, which in exchange leads to more time for checking various design alternatives. This can *improve quality of planned* *development as time savings allow more experimentation* in early stages of urban design process.

By using parametric urban design tools one can quickly produce a large number of solutions in a much shorter time when compared to traditional techniques and procedures. *Merging top-down and bottom-up approaches into a single conceptual framework not only facilitates the early stages of the design process, but it also contributes to a more transparent and responsible urban design.*

Perhaps it would also make sense to investigate if parametric map concept can supplement urban masterplans. This could make the planned development more transparent and open for subsequent changes up to the point of actual architectural design of each building separately.

We plan to implement parametric maps in one of the next releases of Modelur [2], a SketchUp extension for parametric urban design.

REFERENCES

Beirão, JN, Montenegro, N and Arrobas, P 2012, *City Information Modelling: parametric urban models including design support data*. Available at: http://utl.academia.edu/JoseBeir%C3%A3o/Papers/1829358/City_Information_Modelling_parametric_urban_models_including_design_support_data [Accessed August 3, 2012].

Duarte, JP, Beirão, JN, Montenegro, N and Gil, J 2012, City Induction: A Model for Formulating, Generating, and Evaluating Urban Designs in *Digital Urban Modeling and Simulation. Communications in Computer and Information Science*, Springer Berlin Heidelberg, Berlin.

Gil, J, Beirão, J, Montenegro, N and Duarte, JP, 2010, Assessing Computational Tools for Urban Design: Towards a "city information model". In *28th eCAADe Conference Proceedings*, Zürich, Switzerland, 15-18 September 2010, pp. 361/369. Available at: http://cumincad.scix.net/cgi-bin/works/Show?ecaade2010_021 [Accessed September 27, 2012].

Koželj, J and Capuder, T. 1990, *Teorija arhitekture in urbanizma*. Ljubljana, Slovenia, RSS.

Steinø, N, 2010, Parametric Thinking in Urban Design: A Geometric Approach, in *5th international conference of the Arab Society for Computer Aided Architectural Design Proceedings*, Fes, Morocco, 19-21 October 2010, pp. 261/270. Available at: http://aalborg.academia.edu/NicolaiStein%C3%B8/Papers/270860/Parametric_Thinking_in_Urban_Design_A_Geometric_Approach [Accessed September 28, 2012].

[1] http://www.holisticcity.co.uk/

[2] http://www.modelur.com/

[3] http://tiny.cc/ecaade13 - view or download a 6-minute demonstration video of prototype application.