A Grammar-based Procedural Design Guideline Visualization Diagram for the Development of SVA Masdar

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Abstract. Nowadays, a large set of involved planning parties are heavily demanded with the definition of holistic in kind requirement specifications for urban planning sites – so called future cities. However, the resulting amount of specifications for a specific building project poses a great challenge to designers and planners especially when it comes to include this information into their design proposals for a sustainable urban development. These design performance criteria are traditionally expressed in textual and numerical planning guidelines and which are making it difficult to establish a comprehensive and holistic view onto the domain itself. Therefore we present in this paper a design guide visualization method to overcome this situation for the evaluation of design specification and urban layouts in a qualitative and quantitative manner.

Keywords. Sustainable urban patterns; shape grammars; design evaluation; urban planning; design guide translation.

Figure 1
A design guide-line visualization diagram can help to communicate complex interdependencies in urban planning.
Sustainable urban design rules have to be human readable

Our method stands in to reduce the inherited complexity of such requirement specifications with a visual and interactive parametric ‘diagram’ that is based on a generic city system model (Figure 1). It uses grammar-based shape patterns, feature patterns and conditional patterns to describe a large set of regulations that results into a n-dimensional design guide visualization diagram. The method incorporates the context sensitive and stochastic distribution of geometric and meta-informal design features and combines it with grammar-based geometry generation and conditional property verification. The grammar-based implementation is procedurally linked and therefore operating seamlessly from the regional planning scale up to the architectural building scale. Further it allows the user to set-up a city information model environment that includes geometric scopes and entities, conditional behaviors and city properties. The resulting model can be used to interpret the complex nature of sustainable city developments and to communicate more efficiently system specific features to stakeholders of a development. We exemplify our method with the visualization of Foster+Partners planning guidelines for the development of the Swiss Village in Masdar City, Abu Dhabi (SVA) [1], which presents by itself an outstanding prototype for carbon-dioxide neutral future city. The visualization of the SVA serves as a collaborative platform and interactive visualization framework for the SVA’s architects and potential investors. It communicates visually the key properties of the underlying guidelines and enables the user at the same time to reflect local design pattern typologies in cohesion with benchmark criteria for example material masses that are planned to be brought into a certain region of the SVA and the actual GFA that had been achieved. Architects and planners can easily adapt the parameters of the model and iterate through different kind of versions of the model to achieve for example lower energy consumption due to a rearranged placement of solar shades in front of buildings inside Masdar. In this way the model by itself is meant to interface the design guidelines with the final design proposal handed in by the architects. With such an interactive model they can understand the relationships between critical model properties and use these insights for a verification of their own design implementation for example if it is likely to follow the rules of Foster+Partners as the initial ideas for the Masdar planning site. Future work will as well deal with linking the underlying procedural city model with the eco-system-service information from the landscape and environmental planners as well as to combine both with an economic model for the case study in Masdar.

Overview

The paper is structured as follows: The next section presents the related work in the field. Section 2.1 paraphrases the use of the design pattern paradigm in procedural urban modeling. The following section 2.2 explains the process of translating textual and numerical data into an interactive procedural model. Section 2.3 presents the interactive design guideline visualization diagram. Selected case studies are presented in Section 3. Finally, Section 4 addresses conclusion and future work and with Section 5 acknowledgements are made.

Related work

The system refers to the ones by Müller et al. (2006) and Halatsch et al. (2008) with urban planning rule sets and landscape patterns, which can be used for pre-visualization, master planning, guided design variation and for digital content creation purposes of the entertainment industries. The rules and patterns are associated with architectural attributes. Generated geometries follow basic architectural norms according to GIS information. Beirão et al. (2008) already introduced the structure of a shape grammar based supporting tool for urban design, comprising an urban pattern formulation model, a design generation model, and an evaluation model.
In Halatsch et al. (2009) the connections between urban models and grammar-based procedural generation of urban environments and their relevance to urban planning have been introduced. The computational tool for the analysis and generation of our generic city model is based on shape grammars (Stiny, 2006). Shape Grammars have been implemented in the past in the analysis of several historical examples, such as the Palladian Villas (Stiny and Mitchell, 1978). The technical characteristics are directly derived from an attributed shape grammar called CGA Shape, which is suited for applications in computer graphics. It was introduced by Müller et al. (2006) and had been extended by Ulmer et al. (2007), Halatsch et al. (2008) with urban planning rule sets and landscape patterns, which can be used for pre-visualization, master planning, guided design variation and for digital content creation purposes of the entertainment industries. The rules and patterns are associated with architectural attributes. Generated geometries follow basic architectural norms according to GIS information.

With this framework, a wide range of architectural designs and urban layouts can be encoded and detailed 3D models can be generated automatically. Shape grammar rules that create certain architectural configurations can be grouped into collections within libraries. Such libraries exist in literary form and are described as patterns. The use of patterns in architecture is founded on Alexander et al (1977).

An integrated city evaluation model

The implementation of the generic city model is done inside a joint research project with Procedural Inc. [2] by extending their commercially available CityEngine application. We use CityEngine’s CGA shape grammar approach and CityEngine’s GIS interconnectivity to access and exchange data. As inputs design data and functional data (e.g. social statistics, or approximated energy consumption) are used, which are then processed by the system. The output results in a parametric city model by triggering specific design grammar rules during the system’s derivation process. The process is steered by so called patterns, which are imported from standard GIS, CAD and image processing systems or modeled inside the system. In more detail, the output of the grammar derivation process embodies architectural geometry and, or the visualization of spatial relationships between the entities of a city.

A pattern-based modeling approach

Usually, building laws or best practice examples (as a part of empiric planning knowledge) and personal preferences by planners need to be explicitly and implicitly incorporated into an urban design and at different scales, e.g. from regional to building level. The underlying set of data is more or less only available in the form of textbook or table sheet definitions. Furthermore, an integrated computer-based model, which is highly interactive, does not yet exist. Whereas more and more data is recently integrated by municipalities into GIS databases, which offer a unique opportunity to evaluate existing structures or to predict urban scenarios.

Our generic system steps in to create multi-dimensional models that can be used to evaluate aspects of urban performance and it can be used to create visual representations for experts and laypeople at the same time. The underlying system model is implemented in the form of a procedural arbitration of different urban scales that can be seamlessly traversed from regional to building level. This system overcomes the traditional separation of urban data into GIS-based large-scale models and modern CAAD systems’ small-scale building information models. Even more important, the system opens the possibility to have interactive parametric urban models at hand, which can semi-automatically generate 3D visualizations. These urban models are not restricted to contain 3D data representations for one given level of detail. They can easily and instantly modified and adjusted seamlessly. For example, energy analysis on an urban scale can be performed and based on the results new regulations
can be formulated and incorporated into passive energy efficiency guidelines for urban sites. The updated regulations can easily be compared to existing definitions and then evaluated with having, e.g., (a) concrete numbers, (b) a design catalog and (c) a 3D representation at hand. Besides that, authoring software packages for procedural models are more and more integrated with recent GIS-software. In the following we are exemplifying the process and the implementation with Procedural’s CityEngine [2], a sophisticated procedural modeling framework, which can be tightly integrated to ESRI’s ArcGIS [3] and exchange data with recent CAAD tools such as Autodesk Revit [4] and analysis tools such as Autodesk Ecotect [4]. The visual and numeric feedback can be used to validate the procedural model or to refine and rework the model until each performance condition is fulfilled. That leads to the interesting questions how the text- or number-based information from regulations etc. may be translated and integrated into a procedural model. Therefore, we recently discussed the use of design patterns for master planning (Ulmer et al. 2007, Halatsch et al. 2008, and Wissen Hayek et al. 2010). The goal is that a planner may structure an urban model into urban systems and subsystems. Each system can be described by design patterns, which represent statistical functions and values, geometric configurations, conditional decision schemes that interact with and attached property values. So, what are patterns? And how they are used? We differentiate into form effecting and statistical patterns. E.g., grammar-based shape patterns are the geometric reaction of functional or regulative constraints (economical, ecological, sociological). On the other hand, statistical patterns describe value distributions across a certain area, such as a targeted population density distribution steered by building height regulations. Descriptive values such as material names and habitat species are used to steer conditional patterns as well as to report the final performance of the generated urban model. We use a conditional property verification to determine if a value is valid for a given situation. Booleans comparisons between input values are used to traverse through decision trees to find the most tolerable solution.

In more detail we are structuring patterns into the following categories:

1. Grammar-based “shape modifying patterns”: Pure mass functions such as extrusion, block types (perimeter, I-/U-/H-/L-shapes), generic building and plot subdivision that are most dominant and regulative. Generic allocation of zones and the global definition that are expressed by law regulations e.g. maximum building heights, land use mix, solar envelopes or statistical value distribution such as population density.

2. “Feature patterns” cover architectural aesthetics and functional measures on a more subordinate level.
   - “Architectural design feature pattern”: Design of building mass configurations and proportion of building design elements, in conformity, reaction or integration with “Design performance feature pattern”
   - “Design performance feature pattern”: Fulfillment of functional requirements, modeling of ecological constraints such as (a) habitat demands, natural shading functionality, (b) economic constraints such as u-values (energy transmission) per costs per sqm in comparison with grey CO2 stored inside the particular material, or - on a more regional level - distance to work, education and supply, (c) social factors such as accessibility distributions to daily amenities and work, visibility and half-public interaction on building scale

3. Conditional patterns incorporate a behavior model that interact with context sensitive information (e.g. given ecologic, economic and social properties that have been defined in 1. and 2. and are integrated into the procedural urban model). In particular conditional patterns are used to select appropriate features patterns, which will hold the targeted performance crite-
ria for a defined eco-system-services. Statistical functions can be used to provide value ranges that will select predefined feature patterns. Land use, maximum building envelope, building eras, facade typologies or wall materials can be easily defined and automatically applied to the urban model. Especially in situations where only more or less loose definitions exist these values can still be considered as inputs. Therefore the value ranges and the intended reactions have to be initially defined in a conditional pattern.

System elements are connected via GIS database integration. The GIS database serves as a container system to access data for modeling, evaluation and the generation of multi-dimensional spatial data sets. Results from the generation can then be back-looped into the GIS database. The data integration works seamlessly. Several level-of-details (LODs) differentiations are performed to distinguish between different uses of the model. Block-wise extrusions (LOD 1) are used to evaluate large-scale models. Higher resolution LODs provide for instance more accurate material property definitions and geometric appearances as well as a higher granularity for the reporting of building and other elements. This functionality is important since on each scale different evaluation techniques have to be applied for the urban analysis of a modeled area. Each scale can provide feedback and therefore interact with other scales.

The interaction between the interconnected procedural entities inside the model can be used to study interdependencies between properties and special focus measures. The resulting information about the interactions and interdependencies are integrated into a standard GIS database. From the database itself the information of the model, the analysis and the evaluation reports can be easily accessed without special knowledge of our system. Furthermore, the stored information and results can easily be distributed to other software packages, e.g., for CFD simulations (computational fluid dynamics) or 3D real-time visualization environments as well as to rapid prototyping applications.

Translation process: from textual description to city model

The process of transforming abstract regulations into a more understandable and interactive diagrams is structured as follows. First for each scale the top 10 measures have to be identified. These measures should then be incorporated into an ordered list. The measures may be statistical values such as the population density at a given point or a geometric attribute, e.g., the overhang of a building to provide shading on the sidewalk for pedestrians. Based on that order the analyst has to define, e.g. on block scale, a mass model that will be detailed enough to fulfill the initially selected condition. The mass model may be described by a hand sketch (Figure 2). Next
the inherited hierarchy has to be determined. In case of CityEngine it is very effective to define 3D splitting planes that have a hierarchy (Halatsch et al., 2008), which will follow a most generic situation for that system. After the sketches are evaluated, the system can be extended by implementing the parametric description using the CGA grammar dialect. The system behaves context sensitively. For example the user can provide exchangeable GIS-based scenario data on which the system operates in a pre-defined manner depending on the used set of conditional patterns. E.g., the land use mix at a given location can be directly provided by GIS-annotations or by pattern-based functions that define the land-use by the actual relation between population density, job distribution and targeted maximum building height.

2.3 Interactive design guideline visualization diagram

The term ‘diagram’ refers in this present case to the high-resolution volumetric geometry that our method derives. In more detail, the results are ‘pre-buildings’ placed onto geographic referenced positions inside the urban layout of Masdar city. These ‘pre-buildings’ are correct by their syntax but are not meant to present a design similar to a draft that had been proposed by an architect. The diagram shows a potential solution space for the designer. The ‘pre-building’ are structured into several levels of detail (LOD). The initial LOD 0 is used for example to describe the per plot extrusion within the maximum building height envelope that is allowed for a specific development area inside Masdar city. This visualization offers to report as well properties such as the propagated use mix, the total volume and the maximum ‘contact’ surfaces to neighboring plots. LOD 1 adds the overhang property, which describes the delta allowed to be projected onto the street starting from first floor. In LOD 2 and 3 the wind channels and facade setbacks are included with their correct orientation. The stochastic placement of the courtyard buildings are integrated in LOD 4 and the model completes with the placement of a semi-structure facade and the PV panel on top of the ‘pre-building’. On each implemented LOD level geometry and performance properties can be calculated and reported with our method (Figure 3). The resulting data can easily transferred to common spreadsheet application for a further design specification or for the generation of a per plot documentation for tendering processes. The system allows as well to verify the validity of the design guidelines given by the originator and shows with a quantitative feedback that for example the GFA is to high for the given plot or the resulting courtyards are to large and might pose a thread because of the solar radiation in the evaluated area.

Figure 3
Evaluation of the procedural model inside Autodesk Ecotect.
Further case studies

Beside the Masdar example, we tested our presented system with the evaluation of Zurich’s annual energy use and CO2 emission on a building level. As reaction to that study, we developed an – although provocative – vision for a city of Zurich that has no access to any fossil fuels (Figure 4).

Conclusion and future work

This article presents a conceptual framework for procedural modeling and evaluation of alternative urban green space patterns based on ecological parameters. A collaborative platform organized around the 3D visualization of different urban development patterns allows iteratively developing scenarios of sustainable urban development and addressing stakeholders’ concerns. The identification of optimal urban design patterns from the point of view of the stakeholders helps determine key variables strengthening the identity of the city and guaranteeing the sustainability of the dynamic urban system.

This presented technique to create design guide visualization diagrams delivers an abstract and readable description of a complex city system and serves as design decision support tool for architects and planners for a better understanding of interconnected design criteria that are important to reach a certain design performance for a given area. The visualization of the design guidelines for the Swiss Villages of Masdar Abu offers an exciting platform of experimentation as the referenced case studies show.

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