DEVELOPING ALGORITHMIC METHODOLOGY TO VISUALIZE & EVALUATE THE DYNAMICS OF URBAN FORM IN THE EARLY DESIGN PHASE

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Abstract. Advances in algorithmic and architectural methodology is challenging the current practice of conventional and participatory urban design. This paper presents a prototype implementation of a computational urban design tool. This implementation provides a rule-based approach to urban design by developing algorithmic methodology to visualize, analyze the dynamics of urban form in the early design phase. We focus on synthesizing data and demonstrate how data synthesis approaches can be used to support performance analysis at early planning and design stages. The implementation shows a flexible workflow that supports performance analyses and can easily be integrated into design and planning processes.

Keywords. Algorithmic Methodology; Urban Form; Generative Design; Analysis Tool.

1. Introduction

Algorithms have been widely used in architecture, designers have been concerned with the use of computational tools combined with new methodology for the exploration of formal systems (Terzidis, 2006)(Menges and Ahlquist, 2011)(Jabi 2013)(Stouffs and Janssen, 2015). Algorithmic methodology has been incrementally extended to the generative process of urban development using simulation tools and big data analysis. The complexity of urban development demands new urban design methodology with large-scale computation. It is still difficult to comprehensively analyze quantitative information of urban development due to lack of sufficiently detailed information (Beirão and Duarte, 2005)(Ferreira, et.al, 2015)(Stouffs and Janssen, 2016).

Urban design involves many aspects and various disciplines. For the last two decades, planners and designers have been concerned with the use of computational tools with algorithms for the exploration of formal systems. Algorithmic methodology has focused on computational methods of formal exploration and expression. It offers a computational approach to support urban design by providing computational design tools in the early design phase. It has been attempted to readdress formal logic of urban design using new techniques, algorithms, and methods.
One of the problems in the urban design and planning processes is how to integrate generation and evaluation of designs in the early phase. The use of performance analysis, either to inform the design process or to assess design solutions, though available, is still sparse. Part of the problems may be the absence of, or the difficulty in retrieving, sufficient amounts of data to support performance analysis. Nevertheless, there is always a limitation to the data that is readily available and any specific design queries may necessitate data that cannot be obtained by regular means.

Another part of the problem may be the lack of simple and flexible workflows that support performance analyses and can easily be integrated into design and planning processes. Especially when such processes are characterized as dynamic, collaborative and constrained by time, skills and the availability of tools. While various tools and systems are available to support performance analysis within urban planning and design processes, these tend to be neither simple to use, nor flexible in their ways of usage, nor can they be easily integrated with other tools that may serve other parts of the workflow. Modular workflows that can easily be adapted by the user to apply within a particular design context or process are of special interest. Such workflows often rely on various software tools that must be seamlessly connected in order to allow the user to switch back and forth between modeling and analysis.

To overcome the problem, we propose three complementary elements of algorithmic methodology: extracting data, synthesizing data and mining data, as shown in Figure 1. Extracting data refers to data that can be found online, yet not in a readily downloadable or applicable format and requires manual processing or the development of dedicated scripts to extract the data from the source. Synthesizing data refers to data that is generated from existing (design or analysis) data based on assumptions, heuristics and/or typologies. Mining data refers to the application of data mining techniques in order to understand relationships between data.

![Figure 1. Three elements of algorithmic methodology for urban design.](image-url)
The objective of this paper is developing algorithmic methodology to visualize and evaluate the dynamics of urban form in the early design phase. We focus on synthesizing data and demonstrate how data synthesis approaches can be used to support performance analysis at early planning and design stages when urban criteria have been defined only conceptually and still need to be elaborated in terms of planning or modeling. Specifically, we present a rule-based approach to generate relevant building data that can serve to analyze and assess urban plans with respect to relevant criteria, requirements and targets. Such urban form generation must necessarily take into account local conditions, building typologies, codes and regulations. We also address the integration of data synthesis and performance analysis and identify some obstacles for developing integrative workflows on the fly in response to specific questions that may arise in the planning and design process. In urban design, algorithmic methodology can be thought of as analogous to engineering productivity for repeating or continuous processes. There is a clear tendency to seek and explore formal properties as sources of ordering systems in urban design.

2. Related Work

Algorithms play an important role in developing methods for evaluating various visibility-based design characteristics. Progress in algorithmic architecture has been made in supporting parametric and generative design. There has been very little research work reported on the effectiveness of such use of algorithmic methodology in the early phase of urban design.

There are three parallel approaches to develop algorithmic methodology. The first approach is to develop algorithms for parametric and generative designs. The current transition from Computer Aided Design (CAD) to parametric design represents a profound shift in design thinking and methods. Representation is being replaced by simulation, and the crafting of objects is moving towards the generation of integrated systems through designer-authored computational processes (Menges and Ahlquist 2011). Parametric design tools allow designers to specify relationships among various parameters of design models, where algorithmic methodology is developed to come up with interesting design solutions (Terzidis, 2006) (Jabi, 2013). Another approach is the development of rules or algorithms for design evaluation. A generalized parametric model can be used as an analytical device to investigate how different parametric modelling methods provide for iteration (Stouffs and Janssen, 2015). Space syntax theory is developed for analyzing spatial configurations of designs, districts, and cities (Hillier and Hanson, 1984) (Desyllas and Duxbury, 2001) (Batty 2001). The third approach is urban optimization through evolutionary computation (Ferreira, et. al., 2015) (Navarro-Mateu, Makki and Cocho-Bermejo, 2018). It indicates the demand of public participation in decision-making for more accountability on the parts of stakeholders (Healey, 1997). A mixed top-down and bottom-up strategies is developed to integrate each participant’s point of views in urban planning practices (Forester, 1988)(Murray, Greer, Houston, McKay, & Murtagh, 2009).
3. An Example

In order to demonstrate the proposed algorithmic methodology, we present a real-world urban design example to test the implementation. The example has been drawn from the Green Energy Science Village Project, as shown in Figure 2a. We tried to use the local range of Zone A as the experimental implementation, as shown in Figure 2b.

![Figure 2](image.png)

Figure 2. (Figure. 2a) The Green Energy Science Village Project; (Figure. 2b) use the local range of Zone A as the experimental implementation.

4. Research Method

This paper proposes a design method that employs a three-stage algorithm on each participant’s point of interest. By Definition, the geometric, environmental, and social relationships constitute the basis of urban design. These relationships become a complex system with a behavior and efficiency that are difficult to evaluate and predict. Furthermore, being able to establish geometric relationships within urban patterns in 3D modeling software allows us to manipulate geometry’s mathematical definition. Once the definition is established, analyses and manipulations of geometrical variables together with social and environmental ones can be developed through a range of existing plugins. These plugins allow researchers from the architectural and engineering fields to manipulate such a complex mathematical set of relationships, as shown in Figure 3.

![Figure 3](image.png)

Figure 3. A three-stage algorithmic methodology is developed to visualize and analyze the dynamics of urban form.
4.1. Mining Data

OpenStreetMap (OSM) is used as a collaborative tool to create a free editable map of the world. Rather than the map itself, the data generated by the project is considered its primary output. The creation and growth of OSM has been motivated by restrictions on use or availability of map information across much of the world, and the advent of inexpensive portable satellite navigation devices. OpenStreetMap.org is an open/crowd sourced website of mapping data. It allows you to export XML formatted data of a selected area and then Elk will organize and construct collections of point and tag data so that you can begin creating curves and other Rhino/Grasshopper geometry, as shown in Figure 4.

Figure 4. Example for a fast urban fabric prototyping for the Green Energy Science Village Project. The data of the environment including the 3D information of the buildings are imported from open street maps via the Grasshopper plugin Elk2.

4.2. Synthesizing data

In the example, Grasshopper3D served as the primary platform for visual algorithmic modeling. Wallacei is used as an analytic engine for data outputted by the EA, which was developed by Mohammed Makki and Milad Showkatbakhsh. It makes more informed decisions at all stages of their evolutionary simulations; including setting up the design problem, analysing the outputted results and selecting the desired solution or solutions for the final output. The plugin is streamlined to give all of the user efficient access to the data outputted by their evolutionary simulations, and enable clear and efficient methods for analysis and selection - The aim is for users (of all degrees of expertise) to better understand their evolutionary simulations in Figure 5, gain a thorough understanding of the outputted numeric values, and seamlessly extract the optimised data; all within one user interface.
The experiment is inspired by the multiple objectives and goals originally aimed by Ildefons Cerdà (1876). The experiment sets out to generate an urban patch that optimizes for four primary objectives, as shown in Figure 6.

- Larger courtyards for open public spaces (number of mesh faces exposed).
- High solar exposure on the building façades (number of mesh faces exposed).
- Greater block connectivity.
- Urban Density

Building height is defined by the following rules:

The shadow area of the building projected on the road in front of the vertical building line with a slope of 3.6:1 shall not exceed half the product of the length of the road in front of the base and the width of the road, and the maximum shadow shall not exceed the opposite side of the road ahead.

The building base has a permanent open space on the opposite side of the road in front of it, and the shadow area is doubled to calculate the shadow and height as follows: $\frac{L \times Sw}{2}; H \leq 3.6(Sw + D)$

- $As$: The building is projected at the slope of the road in front of the road with a slope of 3.6 to 1 in the direction of the vertical building line.
- $L$: The length of the road in front of the base.
- $Sw$: The width of the road ahead.
- $H$: Building height
- $D$: Horizontal distance from each part of the building to the building line
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As an initial dataset for the algorithm we can use existing spatial configurations, which are freely available through OpenStreetMap. We have an initial data sample $X_0 = x_1; ... x_n$ in a design space $\Omega$, and a corresponding matrix of features (criteria) $F(X_0) = F^0 \in \{0, 1\}^{n \times m}$ (formula by ETH). The aim of the add-on is to assist users to more comprehensively understand how their implemented evolutionary algorithm performs by comparatively evaluating empirical data outputted by the algorithm. Thus possible strategies are presented towards modifying the algorithmic approach in order to gain more efficiency in evolving solutions that generate variation yet simultaneously increase in fitness. It seeks to address this problem through utilizing an analytic approach that aims to untangle and dissect the plethora of empirical data outputted by an evolutionary simulation. The evolutionary algorithm is developed by means of a detailed analysis of each solution and its parameters. Thus it assists the user in making a highly informed decision for the solutions to be selected at the end of the simulation. The computational setup for the design experiments have been developed according to the complexity of the problem being investigated.

In response to the complexity of the urban problems, the experiment utilized a highly simplified phenotype as the base primitive. The complex fitness landscapes present multi-objective problems. We use the Grasshopper plug-in Wallacei to generate a multi-objective evolutionary algorithm that calculates the density and inner courtyard area and the maximum and minimum shadow values. The initial experiment is 50 generation, as shown in Figure 7.

Figure 6. Evolution of maximise shadow on courtyard spaces when optimizing for increasing their areas.
Figure 7. Use the grasshopper plug-in Wallacei to generate a multi-objective evolutionary algorithm that calculates the density and inner courtyard area and the maximum and minimum shadow values.

4.3. Extracting data

Prior to the development of decision-support information system, the feasibility of employing automatic data collection and structuring was estimated according to the algorithm proposed in the intelligent information system. The measurement points are placed in the appropriate position using the defined function to generate model. Practicable frequency of data collection and improvements are explored over traditional methods. Many data are short-lived, so data extraction should be performed daily, which seems technologically possible. The improvements include better timeliness, more extensive body of data, and somehow lower costs.

The system implementation has three major tiers, as shown in Figure 8.

- The data collection module that is responsible for accessing the source websites and grabbing data from web pages. Technical data are removed from cloud databank to optimize the system’s database for storage space, but otherwise the entire web page’s code is saved.
- The processing module that is responsible for structuring the data. Currently it extracts information related to smart grids, smart transportation, green
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buildings, and IoT-enabled communities, as well as divides the properties by urban form, using two thesauri to perform intelligent natural language processing.

- The analysis module that is directly responsible for decision making support and providing capabilities for reports generation, filtering, notifications, etc. The On-line Analytical Processing technology allows interactive mode in data analysis, and Data Warehouse approach permits aggregation of data on multiple dimensions and provides a potent mechanism for creating and running any kinds of queries.

![Figure 8. The schematic diagram shows a three-tiered intelligence system to capture real-time information.](image)

5. Conclusion

We presented a rule-based approach to developing a computational urban design tool that uses algorithmic methodology to visualize, analyze the dynamics of urban form in the early design phase. In order to demonstrate the algorithmic methodology, we implement the proposed method in a real-world example. The example has been drawn from the Green Energy Science Village Project, a real-world smart city using cloud databank, computation, and algorithms to support smart grids, smart transportation, green buildings, and IoT-enabled communities. The implementation include:

- A parametric design platform that combines with computational tools where all the stakeholders can participate and visualize multiple urban scenarios in real-time feedback.
- A novel decision-making platform that combines city-planning level and local neighborhood data to aid participatory urban design decisions.
- A platform that allows for stakeholders to collaborate effectively and engage in complex urban design processes.

The platform is applied within a design studio context. The implementation generates relevant urban and building data from 2D urban plans that can serve to analyze and assess such urban plans with respect to different criteria, requirements and targets. The urban form generation takes into account local conditions and building typologies.

Future research will explore both computational methods and interactive workflows. The former investigation will include a grammar-based data synthesis approach. This approach will require the conception of a relevant representational and description model for the generation and analysis of building information from
urban plans. The model will draw on existing research and development on shape grammars, description grammars, sortal grammars and structures, and be driven by relevant analysis requirements.

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References


