Generative Urban Design Concepts and Methods: A Research Review

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Abstract. Generative design is a fast-growing design approach that is both important and pervasive. This approach has developed after the great digital revolution in the last few decades, especially during the first two decades of the third millennium. Taking advantage of the computational capabilities of modern computers, generative design offers designers the ability to test multiple and complex alternatives by automating design processes using algorithms. The automation makes it possible to manage an ever increasing number of variables and parameters that are difficult to manage manually. This paper presents an attempt to classify the approaches of the generative urban design methodologies applied in the field today, with the aim of highlighting the gaps in the current practices. By reviewing the previous available studies that dealt with the idea of generative urban design, we find that they can be classified according to the approach they adopt in four categories: the first is the approach of deforming or distorting a basic shape proposed by the designer, the second is the approach stemming from the simulation of real urban growth, while the third is the approach of dealing with the urban form on the scale of building blocks without being concerned with the spatial network, and finally the fourth is the approach that emerges from analysing a realistic spatial structure and then proposing modifications based on the results of the analysis. From this review, the paper proposes a new approach resulting from the analysis of a realistic spatial structure to build a generic model that can be the starting point of a synthetic process to be integrated into a generative design methodology.

1. Introduction

Urban design has always been a complex process. This is due to the multiplicity of disciplines involved as well as the diversity of the stakeholders concerned. The long term of the design/realization procedure adds another dimension to the complexity. On the other hand, generative design takes advantage of the ever-increasing computational capabilities of modern computers, giving designers the ability to manage complex processes and a multitude of input variables. The use of generative processes in urban design, therefore, seems of obvious interest. From there an important question arises: what approach to follow to best derive the benefits of the generative process in urban design?

With this question in mind, this paper tries to shed light on the existing efforts that deal with generative urban design, classify them, and then highlight the gaps in the current practice. The classification is made according to the approach adopted to deal with the urban morphology, as input or output of the design process.

By reviewing the previous available studies, we find that they can be classified according to the approach they adopt to deal with the urban morphology into four categories: deforming a basic shape, simulation of real urban growth, urban form as building blocks, and analysing a realistic spatial structure.
2. Deforming a basic shape

In this approach, methodologies are generally based on the parametric generative design. The designer proposes an initial shape that is modulated parametrically to produce a final design alternative. A representative sample of studies that dealt with methodologies of this type is discussed hereafter in chronological order.

2.1. Koenig R. and Christian B. (2004)

In 2004, Reinhard König and Christian Bauriedel [1] proposed a four-level automated module to create an urban fabric (Figure 1). Starting with an Information Level, where the basic information about the initial shape is collected and organised. A second Developing Level is the next step that includes generating a simplified road network. The Building Level is the third step where building blocks are added to the existing grid and minor deformation for the grid can occur. Finally, in the Optimization Level, further adjustments can be made at the network level or the building level with regard to special design criteria.

![Figure 1. The four levels for the computer generated urban fabric. [1]](image)

2.2. Zaha Hadid Architects (2006)

One of the most famous examples of this type of generative methodologies is Zaha Hadid Architects’ winning competition entry for “Kartal Sub-Centre and Kartal-Pendik Waterfront Urban Transformation Project” competition in 2006 [2, 3]. In this urban renewal project for an abandoned industrial area, the designers departed from the proposal to incorporate the existing urban infrastructure, articulating the connections of the main routes identified in the urban regions. The integration of cross-connections (east-west) and (north-south) sets a soft mesh that forms the underlying structure of the project (the basic shape). This elastic grid extends and contracts to adjust to urban conditions and topography of the place (the deformed final shape) (Figures 2 and 3).
2.3. Beirão J. et al. (2009 – 2018)
Starting in 2009, José Beirão, José Duarte, and several research associates presented several research works using shape grammars to generate urban fabrics [4, 5, and 6]. Their methodology uses generally the known shape grammars procedure (initial shape – modification rules – final shape). In 2018, José Beirão and José Duarte presented a proposal for urban development in the suburbs of Sintra near Lisbon [6]. In this study, they applied shape grammar methodology in six steps (Figure 4), starting by the initial state (a) design context, then (b) subtracted buffer zone, then (c) addition of new streets defining a grid of “islands”. The next step (d) applies a regular grid pattern to each “island”. In step (e) a filtration of plots is done. Finally, in step (f) a possible final solution is proposed by controlling the density of dwellings in the area.
2.4. Rakha T. and Reinhart C. (2012)

The aim of this work is to optimize the urban network for walkability for sites with inclinations in different directions [7]. To do so, a generative methodology is produced that starts by creating an initial urban network based on utilizing an orthogonal two-direction grid that searches for minimum values for terrain slopes with control on minimum lot size (Figure 5). Following that, an optimization process in which the grid is altered according to criteria related principally to land use (Figure 6).

![Figure 5. Parametric subdivisions of site respecting terrain slopes and plot minimum sizes criteria. [7]](image1)

![Figure 6. The initial grid is altered according to certain optimization criteria. [7]](image2)

2.5. Shehu M. and Yunitsyna A. (2017)

This study uses parametric design tools for the automatization of the majority of the design process [8]. Its main objective is to shorten calculation times and aid designers. The proposed methodology is based on generating simple urban morphology which can be modified after that to accommodate different building typologies. Another proposed modification is the randomization of the direction of road segments to create an organic-like urban network (Figure 7).

![Figure 7. (a) The initial grid. (b) Alteration of the grid by typological criteria (c) Randomization of the direction of road segments. [8]](image3)
2.6. Nagy D. et al. (2018)
With the aim of providing high profitability, functionality, and sustainability, Danil Nagy and his
research associates developed a parametric generative urban design module [9]. The proposed
methodology starts with an initial shape that they called “design space model” (Figure 8 a) which is a
basic two-directional grid respecting the boundaries of the site. In the following steps, constraints were
added to determine route locations (Figure 8 b), plot sizes, and orientation – implying adding or
removing routs (Figure 8 c), then adding new building blocks and green areas to occupy the remaining
spaces (Figure 8 d, e).

3. Simulation of real urban growth
This approach of generative design methodologies tries to produce algorithms that simulate the
geometrical logic of the emergence and growth processes of an urban form. A representative sample of
studies that dealt with methodologies of this type is discussed hereafter in chronological order.

3.1. Hillier B. and Hanson J. (1984)
In their famous book “The Social Logic of Space”, Bill Hillier and Julian Hanson brought to light the
methodology of “Space Syntax” for the analysis of spatial structures both at the urban and architectural
levels [10]. To develop the theoretical basis of the proposed analytical tools, they put forward a
simulation process for the emergence and growth of urban settlements starting from a basic urban unit
composed of one closed cell (building) attached to one open cell (outdoor space). The algorithm after
that adds new urban units randomly but in the condition that each new unit must have its open cell
attached to an existing open cell, and adjacency between closed cells is permitted. Although the process
is very simple, the results represented a logical configuration of small urban tissues (Figure 9).

3.2. Nickerson, J. V. (2008)
In his paper entitled “Generating networks” [11], Nickerson argues that the city is composed of two
types of networks: the street network which is a Euclidean network depending on metric distances, and
the information network which is based on topological distance and depends on our image of the first
network. Following this idea, Nickerson tested an algorithm that would generate an initial hypothetical
network minimizing the topological cost and maximising the distance (Figure 10 cell 1), then adding details to the network in one hundred steps to minimise the metric distance at the cost of increasing the topological distance. The proposed algorithmic generative module is quite explanatory for the concept but the resulting networks are far from being realistic.

![Image](image1.png)

**Figure 10.** Min. to max. topological cost versus max. to min. distance. [11]

3.3. Popov, N. (2010)
In his paper “Generative urban design with Cellular Automata and Agent Based Modelling” [12], Popov focuses on how urban morphologies of unplanned settlements can be modelled as emergent phenomena. His experiments depart from the same concept presented by Hillier and Hanson [10] illustrated above. His main contribution is to introduce the “Agent Based Model” in the algorithm. This allowed for more variation of results including directions and sizes of open or closed cells (Figure 11). Although the results are more realistic in shapes than Hillier’s attempt, still they are far from reflecting a real life urban settlement.

![Image](image2.png)

**Figure 11.** Various spatial morphologies produced by Agent Based Modelling. [12]

3.4. Al-Sayed, K. (2013 – 2016)
In several studies, Kinda Al-Sayed tried to use Space Syntax methodology in a reverse manner, as synthesis tools instead of analytical tools [13, 14]. This methodology was used to growth projection for
existing urban structures by applying different local topological growth laws then testing the urbanity of the resulting networks by comparing their syntactical qualities to two structures: Barcelona city and a random structure (Figure 12).

**Figure 12.** Growth simulation and comparison of urbanity [13]

4. **Urban form as building blocks**

These studies investigate the possibility of creating three-dimensional urban shapes based on the application of basic rules. These studies pay little attention to the structure of the urban space network. The most important studies that offer or discuss methodologies of this type are (in chronological order):

4.1. *Alchalabi, O. Q. et al. (2009)*

This study is axed on generating alternatives of the urban fabric by the reuse of the geometrical shapes of individual buildings in the organic urban fabric (Figure 13 a, b). The urban fabric is simulated by simply combining individual buildings into a regular grid then randomly rotating some of the buildings (Figure 13 c, d). The result in fact has no urban network, which makes it far from being considered as urban fabric.
4.2. Steino, N. & Obeling, E. (2014)
In this study [16], the researchers developed a parametric generative design tool. The methodology divides the generative process into six steps, which are 1. Terrain, 2. Street pattern, 3. Block subdivision, 4. Site layout, 5. Building envelope, and 6. Facade style. Nevertheless, in the application of the methodology, only steps four to six were integrated into the generative process while the street pattern was designed manually and blocks were not subdivided (Figure 14).

**Figure 14.** Application of steps four to six of the generative methodology – (a) generating site layout, (b, c and d) alternatives for building envelope and façade style [16]

4.3. Vidmar, J. & Koželj, J. (2015)
This study [17] focuses on building regulations and builds a parametric tool to encode them. The study presents after that some tests for generating urban structures that respond parametrically to the coded regulations (Figure 15). The urban layout and network were out of the point of interest of this study.
4.4. Chowdhury, S. et al. (2017)
The main concern of this study [18] is similar to the previous one. The proposed methodology of
generative design depends on the parametric encoding of building regulations such as density and height
(Figure 16). The result is an interactive model at the urban block level, which can serve as a discussion
platform around urban development. The urban network level is not a part of this methodology.

5. Analysing a realistic spatial structure
According to this approach, the generative methodology starts from the results of an analytical process
of the urban fabric spatial structure, as it proposes changes to the spatial structure of the urban fabric in
connection with the numerical results of the analysis. From the review of available literature, only one
study follows this approach:

5.1. Schaffranek, R. & Vasku, M. (2013)
With (network improvement) as a goal, this study [19] presents a generative methodology that exploits
the results of Space Syntax analysis to define spaces that need to have their syntactical properties
improved (Figure 17 b). The next step is to apply methodical changes to the network to achieve the
desired improvement. In (Figure 17 c), the spaces with low integration were connected to the nearest
high integration spaces by axes linking the midpoints of the concerned spaces. The results of the analysis
(Figure 17 d) shows the successful improvement of the desired spatial quality. Unfortunately, such
modification does not take into consideration real-life issues like the needed subdivisions of building
blocks and the unpractical resulting block forms.
6. Conclusions and Recommendations

This paper tried to classify generative urban design methodologies and to point out the cons and pros of these methodologies. The proposed classification divides the generative urban design methodologies according to the approach that they adopt in four categories. The first category includes studies using the approach of deforming or distorting a basic shape proposed by the designer. The second is the approach stemming from the simulation of real urban growth. The third is the approach of dealing with the urban form on the scale of building blocks without being concerned with the spatial network. Finally, the fourth is the approach that emerges from analysing a realistic spatial structure and then proposing modifications based on the results of the analysis.

For the first category (deforming a basic shape), generative methodologies that follow this idea are widely used. This is due to the relative simplicity of the procedure and the promising results. The negative point is that for such methodologies to be practical, the initial shape must be very simple and the resulting urban network is sometimes not even realistic, or at least of simplified structure.

Regarding the second category (simulation of real urban growth), as urban growth is a very complex process, studies simulating real urban growth were in general simplified and hence unrealistic. One advanced endeavour is the work of Kinda Al-Sayed. Nevertheless, the applied methodology does not give clear control upon setting the objective of the proposed methodology of growth.

The studies of the third category (Urban form as building blocks) present valuable methodologies at the level of the design of urban buildings and urban blocks. However, no interest is given to the level of the urban network. This makes the utility of these methodologies limited in scope and must be applied within small-scale developments.

The fourth category (Analysing a realistic spatial structure) is a promising approach. However, the application of this method needs to be developed to arrive at realistic solutions.

From an overlook at the mentioned approaches, we find that no approach starts from analysing the existing urban fabric to capture its generic properties and translate these properties into a parametric generative model to create alternatives having the same generic properties of that fabric although different in other design parameters. To cover this gap, a fifth approach to generative urban design can be proposed. The new approach needs to deal with the generative urban design in two methodological steps. The first step would be the morphological analysis of the existing urban fabric in the aim of creating a simplified but informative (generic model) for the fabric. The second methodological step
would be to create a (generative model) in which the morphological qualities coded in the generic model can be adjusted parametrically to enable the control of the design objectives related to the generic morphological qualities of the generated urban fabric. This paper is part of a larger research project that aims to test the proposed new methodology. A successful application of the new approach could open new horizons in the methodologies of generative urban design.

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