The City Biosphere

A novel theoretical and experimental methodology for the identification of catalysing mutations in city generation, assembly and development

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Abstract. This paper introduces a new experimental city generation, assembly and development platform, the urban mutations platform. We describe in detail a methodology for modeling urban systems and their dynamics, based on self-organization principles. The urban area is seen as an organism comprised of different “body parts”, the urban subunits. Upon creation of an initial 3D urban environment, it is possible to add to the subunits the so-called mutations, i.e. structural and functional components that can have beneficial or detrimental effects to the future city development. After addition of the mutations we allow the city to reorganize itself and observe possible changes in the urban configuration. These changes can be directly correlated to the added mutations and their urban qualities and allow us to probe the effect that different structural and functional elements have on the dynamic behaviour of the city, when placed at specific locations. Keywords. Self-organization; mutation; urban qualities; urban grid; urban mutations platform, UMP.

INTRODUCTION
Organisms are complex systems, comprised of many different subunits, each serving a specific function. They are capable of, among others, response to stimuli, growth and development, and regulation of their internal environment. Proteins (from the Greek “πρώτος”, which means “primary”) are a fundamental part of all living organisms. They function as major structural components of body tissues (muscle, hair, collagen, etc.), and as enzymes and antibodies (Stryer, 1988). Proteins are assembled through the step-by-step addition of an array of 20 essential compounds called amino acids. The order in which the amino acids are added onto the growing protein chain is determined by the organism’s genetic code: each amino acid is the combination of 3 bases of the DNA. In order to mutate a specific amino acid in a protein, a scientist needs to follow a detail deconstructive and reconstructive process: a subunit of the amino acid sequence containing the targeted amino acid is constructed and at least one of the DNA bases that make up the specific amino acid is exchanged; finally, the original subunit is replaced by the newly constructed one in the protein (Georgakopoulou et al., 2009). The amino acid sequence of a protein defines its three-dimensional structure and consequently its function.

Cities have often been compared to organisms in literature. In her book “The Death and Life of Great
American Cities” (1961), Jane Jacobs writes: “Cities happen to be problems in organized complexity, like life sciences. They present situations in which half a dozen or several dozen quantities are all varying simultaneously and in subtly interconnected ways”. Urban scientists have since long understood that the problems leading to a degradation of a city are too complex and have roots in too many different aspects of the city’s structure and function to be promptly identified and successfully treated simply through observation. They have therefore often turned to using techniques taken from biology and other life sciences. Very common is the analogy to living organisms and their cardiovascular networks, when studying urban networks such as traffic, energy and other resources (Odum, 1971; 1973; Samaniego and Moses, 2008). The analogy is also made when studying the ecology of a city system, where scientists often refer to the city’s metabolism and footprint (Decker et al., 2000; Luck et al., 2001; Decker et al., 2007).

Similarly to life sciences, where large amounts of complex data need to be analysed and understood, various computational methods have been employed by scientists in order to simulate the dynamics and describe the complexities within a city. Land use patterns as well as traffic organization are commonly studied using CA (Simon and Nagel, 1998; Batty et al., 1999; van Vliet et al., 2012; Vasic and Ruskin, 2012), while more computational methods and models, such as self-organizing maps (SOMs), fluid and system dynamics, agent simulations and combinations thereof are emerging in order to tackle a city’s social, environmental and structural problems (Castilla and Blas, 2008; Tuia et al., 2008; Wang and Feng, 2011; Lauf et al., 2012).

This paper aims to bridge the gap between life sciences and urban sciences and introduce an interdisciplinary approach towards a comprehensive theory, which can be used to study cities with diverse structural and cultural characteristics and at different stages of evolution. A typical way of studying complex systems is by reducing the problem into smaller sub-problems and examining one specific area of the system at a time. Thus it is possible to gain a thorough understanding of the functioning of each part (area / factor) before gradually putting the pieces back together and studying the interactions within the whole. The main goal in this study of the urban environment is to develop a theory according to which it is possible to identify “mutations”, i.e. single factors that can affect the well being of a city.

**METHODODOLOGY**

The inspiration for this project is derived from higher organisms, these very complex biological systems that function with great efficiency and in which every part has a specific role and performs a specialized task. Higher organisms are comprised of amino acids, which come together to construct proteins, essential elements of the organism’s body parts and functions. In our analogy body parts are compared to different urban subunits, proteins to specific structural and functional urban elements (hereby called “mutations”) and amino acids to urban qualities (Figure 1).

In particular, our framework works as follows: at the first step we consider four different subunits: residential, industrial, old city and commercial. The generated subunits actually assemble into a city only when their placement in space is optimal; failure to assemble may signify i.e. that the subunits are too far apart and don’t “see” each other, or that conflicting subunits are placed too close together (i.e. according to the areas mentioned above, an industrial subunit right next to a historic centre).

In an analogous way that proteins are made up of amino acids whose properties give the protein certain attributes, city areas are seen here as comprised of structural and functional elements (the mutations), each encompassing several urban qualities that make up the area’s character and function. As soon as the city has formed out of its assigned urban subunits, the mutations are added. Essentially this means that certain areas within an urban subunit will be altered. Mutations are structural or functional city elements, such as roundabouts, play-
grounds, landmarks, pedestrian areas, (air)ports, changes in land use or zoning laws, but also abandoned industries, inefficient buildings, dark alleys, run-down squares, criminal activity or demonstrations (Figure 2). Eventually, geographical elements can be included.

As mentioned above, every mutation encompasses a series of urban qualities, each bearing a grade from 0 to 1. In our framework, these grades are translated into characteristic colour components. The urban qualities will be eventually selected and graded after thorough investigation of the related literature (see an example of urban qualities in literature in Table 1). Currently, in order to test our framework and experimental platform, we have completed a first selection of possible urban qualities, which is shown in Figure 3 (Koltsova et al., 2012).

Effectively, mutations are characterized by a distinct multi-dimensional colour code (Figure 4), each component reflecting the grade of an urban quality. As mutations are added to the city grid, their colour codes interact and reorganize themselves according to self-organization rules (Kohonen, 1982a; b; 1983; 1985; 1990).

Self-organization is commonly seen in literature as a way to organize complex data by clustering observations with similar attribute patterns in space (Spielman and Thill, 2008). In the field of architecture and urban planning it is commonly used as a method to manage and visualize data such as demographics or urban sprawl (Spielman and Thill, 2008; Arribas-Bel et al., 2011), to create and distort meshes (Castilla and Blas, 2008), or for identification of patterns of urban functions (Diappi et al., 2004);
the latter study bears the closest resemblance in the use of self-organization as the one described here, however it is not used as a direct tool for configuring city organization.

In this study self-organization acts as the underlying mechanism according to which the city areas and functions are (re)distributed every time a new mutation is inserted into the urban plan. The mutation-specific self-organizing codes distort the city grid and quantify (on the city level) parameters such as:

- the type of disturbances caused (negative, such as pollution, criminality, traffic, abandonment, but also positive, like job creation, commerce, cultural life),
- the gravity of each disturbance (how strong is the mutations’ influence, from severe to benign),
- the size of the affected area (may vary depending on the mutations’ position in the city).

PRELIMINARY RESULTS AND DISCUSSION
The developed experimental platform – the urban mutations platform, UMP – is based on the attractive city generator (Augustynowicz et al., 2010): an interactive tool for the creation of virtual cities using

Qualities: sociability: 0.6; accessibility: 0.2; green space: 0.1; openness: 0.2; imageability: 0.3.

Qualities: sociability: 1.0; accessibility: 0.8; green space: 0.6; openness: 0.4; imageability: 0.9.

Qualities: sociability: 1.0; accessibility: 0.7; green space: 0.4; openness: 0.6; imageability: 0.8.

Qualities: sociability: 0.4; accessibility: 0.9; green space: 0.2; openness: 0.6; imageability: 0.5.

Qualities: sociability: 0.1; accessibility: 0.1; green space: 0.5; openness: 0.1; imageability: 0.1.

Qualities: sociability: 0.8; accessibility: 0.9; green space: 0.5; openness: 0.7; imageability: 0.5.

Qualities: sociability: 0.7; accessibility: 0.7; green space: 0.9; openness: 0.7; imageability: 0.3.
physical objects (Figure 5). Each object represents a different city area, which is characterized by a specific colour. The recognition of a certain colour and its assigned area prompts the creation of a specific pattern of the urban grid. Upon creation of the city grid, characteristic buildings rise on each block. The tool is created on Java-based Processing (Fry and Reas, 2011) and uses L-systems (Lindenmayer, 1968a; b) to distort an urban grid based on the movements of the coloured objects on a given surface. The output is a growing urban environment, which, though not thorough in its urban rules, gives the user insight into the complexity and dynamics of urban evolution.

The attractive city generator has several distinct advantages that make it a very good basis for the newly developed platform. Primarily, it has a robust user interface which is able to respond to changes made by the user with minimal delay: when a user changes the configuration of the coloured objects, the platform reads the new input and almost simultaneously translates it into a new three-dimensional urban environment, thus providing direct feedback to the wishes and visions of its users. For this, it uses an efficient colour-recognition code, which also makes it very versatile in terms of having different types of colour-based input sources. Additionally, it features minimal 3D design that allows for a certain level of abstraction in the final result, since the goal is not to recreate exact cities in 3D, but to reproduce the general characteristics and ambience of a certain city.

On the other hand, the attractive city generator did not feature any educated interaction among the urban subunits, other than a very simple shrinking or growing of certain areas depending on the position of the rest. Moreover, there was no possibility to intervene within a subunit, so the city was eventu-
ally made up of a clear segregation of four distinct areas.

In the UMP we are exploiting all the advantages of the attractive city generator, while addressing its disadvantages. The platform is able to translate the colour and position information of input markers – each signifying a different urban subunit and, later, mutation – into a dynamic city pattern. However, its main strength and contribution is in the analysis of the interaction between the different subunits, using the rules of self-organization. In addition, the users are able to intervene within the structure of the subunits by adding different mutations. The design of the buildings remains minimal, to ensure at all times an immediate and dynamic response of the city to user input.

The self-organizing code is colour-based and tries to balance the clustering of similar colours with retaining the overall topology of the grid. The first version of the code is kept very simple. Each cell in the grid is characterized by four colour dimensions: red, green, blue and yellow. The radius R of the interaction is limited to one fifth of the grid’s diagonal and it drops by 1/3 with the addition of a mutation, in order to keep the mutation effect more localized. The time constant depends on the number of iterations, while the radius decay and learn decay are typical exponential decays. Finally, the influence among the cells is also exponential and depends on the distance between two nodes. The parameters that define the interaction between the cells are summarized in Table 2. In the following examples we have started with a very basic setting. We have initialized the self-organized grids based on different urban morphologies, i.e. city centre (depicted in red), commercial centre (in blue), industrial area (green) and residential area (yellow). Next we allowed the areas to interact, by running the first round of iterations. Once the grid has stabilized, various mutations are added in parts of the new grid – seen as small pools of colour. The mutations are also very basic, which means each one represents an area fully, and no mixed-qualities mutations are allowed. On the second round of iterations, the mutations are now interacting with the areas. The result can lead to very different outcomes in terms of the areas’ character and reorganization upon the addition of mutations, depending on the position of the mutation and the size of the various areas.

In the first case, addition of the mutations leads to a complete reversal of the affected areas and the creation of a new area (Figure 6a). A city-centre-type mutation (i.e. cultural centre or theatre depicted in red) in an industrial area (green), in combination with an industrial-type mutation (i.e. a new industry, in green) within a similar-sized city-centre area (red), leads to the reversal of the two. At the same time a new residential area is created upon addition of a residential-type mutation (i.e. favourable landuse and zoning laws) in previously empty plots.

In the second case (Figure 6b) we have partial change of a large industrial area into a commercial one by addition of a commercial-type mutation (i.e. a commercial skyscraper or office building). Moreover, addition of a residential-type mutation in a small area of empty plots, leads to the creation of a new

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>R, G, B, Y</th>
<th>n = c</th>
<th>constant number of iterations</th>
<th>constant learn rate</th>
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</thead>
<tbody>
<tr>
<td>number of iterations</td>
<td>n = c</td>
<td>constant number of iterations</td>
<td>constant learn rate</td>
<td></td>
</tr>
<tr>
<td>learn rate</td>
<td>L = c</td>
<td>constant learn rate</td>
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<td></td>
</tr>
<tr>
<td>radius</td>
<td>R = (h + w) / R₀</td>
<td>h and w are the grid’s height and width</td>
<td></td>
<td></td>
</tr>
<tr>
<td>time constant</td>
<td>t = n / logR</td>
<td>R = 5 and triples with mutation addition</td>
<td></td>
<td></td>
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<tr>
<td>radius decay</td>
<td>R_{dec} = R x e^{-n/t}</td>
<td></td>
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<tr>
<td>influence</td>
<td>e^{-d²/2R_{dec}n}</td>
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Table 2
Self-organization parameters, as set for the preliminary results of the UMP.
Figure 6c presents an example where an industrial area is added in empty plots, in the same way as the residential areas in the previous examples, while the addition of a city-centre-type mutation within a well-developed commercial area leads to no changes, as there is already a large city-centre nearby. Finally, Figure 6d shows an example where the mutations added have no effect in the already well-established and balanced areas.

Above we have illustrated the proof of concept of how to use self-organization in order to probe city development and dynamics. The results so far show that a certain level of self-organization can explain changes that happen in an urban expanse on a larger scale and long timeframe. In order to identify to which extend these results are able to describe real city dynamics, further analysis must be undertaken. This will be discussed further in the outlook section.

OUTLOOK
Several important steps are still necessary in order to verify and complete the UMP. On a first level, it is central to introduce the possibility to add “mixed-qualities” mutations, such as the ones described in figure 3, rather than the basic one-colour mutations used in the proof of concept. This will allow for more diversity in the types of interventions into the various city areas, which corresponds better to reality. Moreover, it will also add diversity within the four, currently very strictly assigned initial areas.

The final urban grid patterns can be analysed by calculating their first and second derivatives. Measurements and calculations of difference spectra (patterns) is a common practice while studying the functional characteristics of complex systems (Georgakopoulou et al., 2002; 2003; 2006a; b). By subtracting the patterns created by a mutation event and the initial grid, or by two different mutation events, we derive the difference pattern, which contains characteristic information on the effect of each event on the city. Comparison of difference patterns allows for grouping seemingly irrelevant mutation events and can lead to a deeper understanding of the underlying reasons causing specific city disturbances. Eventually, a list of mutations will be compiled, indicating which are the structural elements of great importance that are unique in their properties and functions.

In order to verify the ground-truth of the results of self-organization in a city, a historical analysis on specific urban areas will be undertaken, using historic maps and information on urban development plans throughout the years. The long-term and large-scale effects of introducing new structures within these areas will be probed. These will be compared to the results derived from the self-organization results of a similarly arranged city. Thus, we will be able to fine-tune the input parameters that describe the self-organization code and estimate the exact extend to which this technique can simulate the future of a city.

The UMP can then be extended as a city-planning tool, with an improved user interface, which will take advantage of the latest technologies in touch screens and digital communication. The users will be able to test their planned development and add urban as well as geographical elements. The Value Lab of the chair of Information Architecture will be used for the development of a program using the touch table interface. In the future, the ICG should be possible to use on any tablet or computer, for easy access to all professionals and it will become an invaluable tool for planners and stakeholders.

REFERENCES
Batty, M, Xie, Y and Sun, Z 1999, ‘Modeling urban dynamics through GIS-based cellular automata,’ Computers, Envi-
Examples of different urban configurations before and after the addition of urban mutations. Top left: initial user-fed organization of four areas: city-centre (red), commercial centre (blue), industrial (green), residential (yellow). Top middle: first round of iterations leading to a self-organized urban expansion. Top right: the 3D representation of the urban area after the first round of iterations. Bottom left: mutations added by users. Bottom middle: resulting urban expansion after the second round of iterations. Bottom right: 3D representation of the final urban area.

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Figure 6 continued

Examples of different urban configurations before and after the addition of urban mutations. Top left: initial user-fed organization of four areas: city-centre (red), commercial centre (blue), industrial (green), residential (yellow). Top middle: first round of iterations leading to a self-organized urban expansion. Top right: the 3D representation of the urban area after the first round of iterations. Bottom left: mutations added by users. Bottom middle: resulting urban expansion after the second round of iterations. Bottom right: 3D representation of the final urban area.

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