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# A parametric landscape urbanism method: The search for an optimal solution

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**Abstract**

Through ecological awareness, different methods have been investigated to explore the relationship between nature and design. Additionally, digital techniques and methods have begun to dominate all fields of professions, including design disciplines. Landscape is an integral part of a city's public domain. The concept of Landscape Urbanism prioritizes landscape over building design in urban planing through the use of advanced digital techniques. Although there are studies and projects in this field, they lack a method that can be implemented for the organizational principles of a masterplan and the distribution of green-areas by creating iterations. A parametric landscape urbanism method has been developed and applied as the concept of a self-sufficient micro-nation located in Europe. The methodology uses principles that consist of three stages: defining the site's constraints, generating computational geometry, and the optimization process, which uses evolutionary algorithms. As a result, a solution space is generated by creating iterations for green area distribution and determining their green area ratios. The method can potentially be applied to other site domains and optimization problems.

**Keywords**
Computing, Evolutionary algorithms, Form generation, Landscape urbanism, Parametric design.

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## 1. Introduction

Ecological awareness has been on the rise since the last century. Different methods have been investigated to analyse the relationship between ecology and design in order to find solutions for environmental problems and create sustainable living (Erdem, 2012). The understanding of landscape architecture is multi-faceted and includes the knowledge of ecology, horticulture, land science, geology, soils, hydrology, botany, biology, chemistry and physics. Landscape architecture deals with open space, the public realm, and the relationship between human activities and natural environment (Holden and Liversedge, 2014). As seen from Peter Cook's perspective, landscape and architecture is a single environment and cannot be separable (Spens, 2007).

Digital computer models are extensively used in all design disciplines, including landscape architecture and urban planning. They are mainly used for visualization purposes and the evaluation of options and simulation, through computer-aided design (CAD) and geographic information systems (GIS) (Ervin, 2001). Computer-based simulation tools are used for various purposes, such as assessing the visual impact of land-use decisions (Bergen et. al, 1998) and modelling and monitoring landscapes (Eşbah et. al. 2011). Landscape is composed of six elements: terrain (land form), vegetation, water, structures (both architecture and infrastructure), people and animals, and atmosphere. The static geometric model should be able to respond to structural loads or hydrologic models. Algorithmic and data-structuring techniques are used to represent complexity in models (Ervin, 2001).

Architecture has been influenced by nature in its forms and structures and in the inner logic of its morphological processes. According to Frazer (1995), architecture is literally part of nature, which means the man-made environment is a major part of the global eco-system and that man and nature share the same resources for building. Based on Darwin's approach, the world is undergoing continuous evolution and change. Evolutionary architecture deals with form-generating processes in architecture through a scientific search for a theory of morphogenesis in the natural world. Computers are required to simulate complex natural processes. The development of computing has been significantly shaped by the building of computer models used for simulating natural processes. Holland questioned natural and artificial systems in terms of how evolution produced increasingly fit organisms in highly unstable environments. The evolutionary model is considered a generative technique (Frazer, 1995).

The basis of computation is varying parameters that respond to different iterations of an algorithm (Frazer, 2016). According to Schumacher (2009), parametricism is a style rooted in digital animation techniques. Its latest refinements are based on advanced parametric design systems and scripting methods that are applied to all scales, from architecture to urban design. Parametricist urbanism aims to construct a new logic to interrelate multiple urban systems, including fabric modulation, street systems, and a system of open spaces (Schumacher, 2009). Although there is a contrary perspective on parametricism, namely that the use of parametrics is only an efficient way of flexibly describing geometry and does not necessarily lead to any style (Frazer, 2016), parametric design systems, along with advanced geometric modelling capabilities of computers, lead to complex and articulated organizational and formal outputs. Similarly, Landscape Urbanism focus on urban planning by prioritizing the landscape design of the city over the design of buildings through the use of advanced digital techniques, including parametric design systems.

Although there have been projects and research undertaken in landscape urbanism, there is a necessity to develop a method that can be implemented for a masterplan by selecting the critical parameters related to the distribution and optimization of green areas with the intent of creating a self-sustained ecological system. The concept of landscape urbanism and an algorithmic approach is discussed further to get a better understanding of the proposed methodology.

### 1.1. Landscape urbanism

Design and planning need to respond to environmental issues, including the decline of natural resources, pollution, the greenhouse effect, and ozone layer destruction. The design of ecologically sustainable cities is concerned with the process of structuring public space (Moughtin and Peter Shirley, 2006). Although buildings are considered the focus on issues related to sustainability, landscape plays an integral role in the generation of sustainable cities because landscape as a built piece of infrastructure obtains a critical task in the performance and livability of a city and needs to be evaluated as an important organ within the city rather than as leftover spaces between buildings (Schwarz, 2011). Although designers are aware of issues related to sustainability, sustainable design is not always seen as representing design excellence or innovation. Early examples were mainly focused on technologies that produce energy and recycle waste (Mostafavi and Doherty, 2010). Additionally, the relationship between nature and architecture needs to include physical and biological processes beyond aesthetic considerations (Pallasma, 2007).

The concepts of Landscape Ecology, Ecological Urbanism and Landscape Urbanism aim to find ways to integrate nature with architecture and urban design. While landscape ecology intents to challenge the role of human impact on landscape structures and functions, ecological urbanism aims to balance conflicting conditions of ecology and urbanism. In landscape urbanism, the landscape is the main driver of urban design instead of some basic building blocks that combine ecology with stimulating designs generated through the use of advanced digital techniques (Surya, 2016). Landscape has emerged as a model for contemporary urbanism today that is capable of describing decentralized urbanization in the context of complex natural environments and that obtains a deep concern for landscape's conceptual scope, territories, ecosystems, networks and infrastructures aside from vegetation and earthworks by organizing large urban areas (Waldheim, 2006). Landscape urbanism is described as a process-oriented approach above the form-oriented approach that has been driven by the arguments of Rem Koolhaas on urbanism. He describes urbanism as conditioning, fluid, and process-oriented (Palmboom, 2010).

Landscape begins with the ground, which is a three-dimensional entity. The relationship between the infrastructure of a city and natural systems motivates the discussion of urban strategies through the development of networks of ecological systems (Waldheim, 2006). The development of the landscape (dikes, drainage and reclamation) and the shaping of the cities (street plans, canal systems), defensive systems (water defences, fortifications) and infrastructure (canals, harbours, roads and railway lines) are interconnected elements (Palmboom, 2010). There are methodologies developed for ecological infrastructure as a basis for design, which was pioneered by landscape architect Frederick Law Olmsted. The aim of landscape urbanism is to produce new open-space morphologies by generating, integrating and mediating ecological systems with a well-developed understanding of the ground as well as deploying a fluid built form that incorporates a new infrastructural sensibility (Castro et. al., 2013).

### 1.2. Algorithmic approach

The term computation is usually confused with the term computerization. While computation includes mathematical and logical methods, computerization is concerned with the processing and storage of existing information (Terzidis, 2006). Computational design (CD) has started dominating architectural design process parallel to technological developments that requires solving problems using a system's integrity. CD was developed as a sub-discipline that aims to solve complex problems in architecture through its advanced computation capacities. Its techniques enable the establishment of systems, even those with complex properties, in a holistic manner. Computation obtains an algorithmic logic that is deterministically rational, decisive and systematized (Çolakoğlu, 2006). In line with this, parametric design is based on manipulating a particular form or study by changing its parameters and creating iterations (Kvan et. al. 2004), as seen in Antoni Gaudi's work on a post-analysis of Mark Burry (Frazer, 2016). However, the capabilities of the current tools in CD in the design process have limitations, which are continuously being improved upon.

Landscape urbanism offers the reinterpretation of the traditional conceptual, representational and operative techniques with a new language by entering the digital space of computers (Waldheim, 2006). Parametric design is a strong medium that enables people to generate a solution space through iterations, allowing various design alternatives to be tested in the process by generating extensive organizational and formal outputs. Although parametric models enable us to create systems with objective criteria, there are a comprehensive amount of issues that need to be addressed fully during the design process such as site constraints, program, performance requirements, planning regulations and climate. Therefore, simplifying the parametric model plays a critical role. The design decisions are generally made by the designer using the solution space driven by the parametric model and based on the combination of objective criteria and knowledge and his or her experience.

## 2. Methodology

A parametric landscape urbanism method has been developed and applied to the concept of a self-sufficient micro-nation located in Europe by specifying the critical parameters, rules and relationships of the system that uses principles driven through natural systems. The methodology is implemented for the organizational principles of a masterplan and distribution of green areas by creating iterations consisting of three stages: defining the site constraints (2.1), the generation of the computational geometry (2.2) and the optimization process (2.3).

A series of digital tools are used in the process for three-dimensional (3D) geometric modelling, parametric design and optimization purposes. The two-dimensional (2D) CAD plan from the Autocad is inserted into the Rhinoceros 3D geometric modelling software. Additionally, the Grasshopper parametric design tool and the Galapagos optimization engine for evolutionary solver are operated in the process.

Although applied rules introduce an organizational logic regarding the masterplanning (including the parcel sizes, dimensions and green area distributions), there are various other parameters to be considered during the design of a masterplan. Critical parameters related to green area distribution are selected for this research in order to simplify the model and reduce the computing power and runtime required.

### 2.1. Defining the site constraints

The site has a mild climate and is located between Croatia and Serbia on the west bank of the Danube river. The area of the site is approximately 7 km$^2$ (Figure 1). The nearest towns to the site are Zmajevac in Croatia and Bački Monoštor in Serbia. Additionally, the topography is almost flat.

According to the design brief, the masterplan should reflect the artificial ecologies concept by offering a nature-like built environment with a systemic settlement plan. The density potential is currently 340,000 citizens.

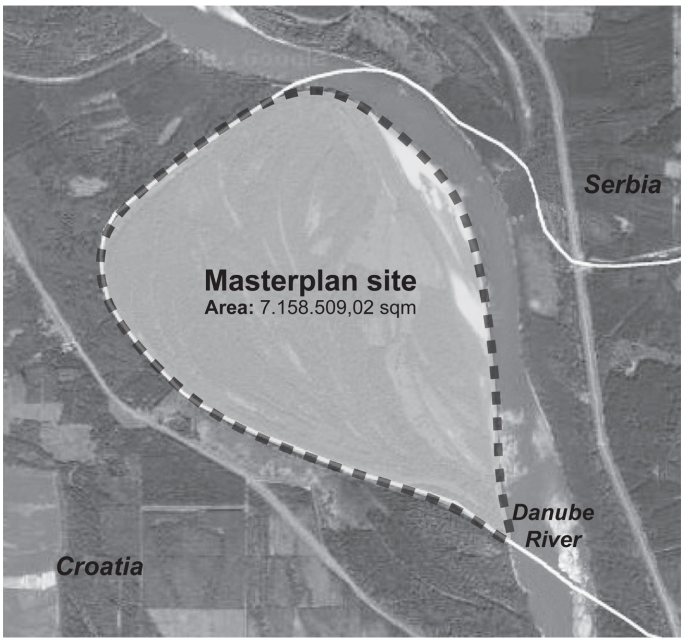


*Figure 1. Masterplan site.*

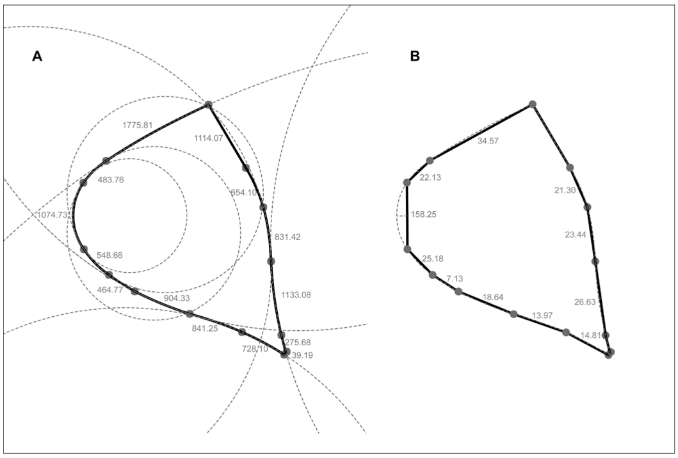


***Figure 2.*** *Analytical study of the NURBS curves forming the site: A- The length of the segments, including arches & straight lines; B-Perpendicular length of straight lines to the segments, by connecting starts and ends of segments.*

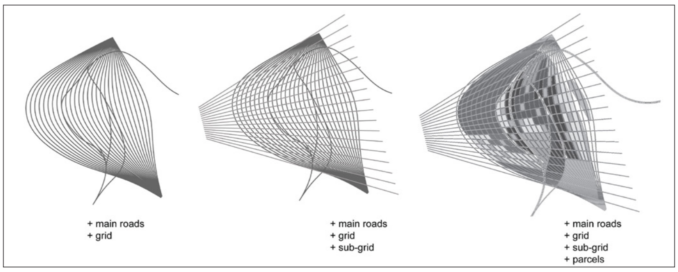


***Figure 3.*** *Generation of the masterplan geometry.*

A dense urban configuration, which could potentially be developed vertically, is suggested by the design brief.

During the design process, the site boundaries of the masterplan area and the major roads in Croatia and Serbia are investigated. It is necessary to generate a main spine to connect the masterplan site to the other countries and cities.

### 2.2. Generation of the computational geometry

Non-uniform Rational B-Spline (NURBS) is a standard form of description for curves and surfaces and has the ability to determine all types of geometries, including complex forms. NURBS obtains advanced mathematical and algorithmic properties (Piegl and Tiller, 1997). The equation of a NURBS curve (1) can be described as the following, where $p$ is the order, $N_{i,p}$ are the B-spline basis functions, $P_i$ are the control points, and the weight $w_i$ of $P_i$ is the last ordinate of the homogeneous point $P_i^w$ (Wolfram, 2016):

$$C(t) = \frac{\sum_{i=0}^{n} \mathrm{N}i,p\,(t)wi\,\mathrm{P}i}{\sum_{i=0}^{n} \mathrm{N}i,p(t)wi} \tag{1}$$

The shape of the masterplan is analysed geometrically. The site has an irregular geometry, with dimensions of approximately 2.9 km and 3.8 km in the x and y directions, respectively. The geometry is formed by two free-form NURBS profile curves, which are described using analytical methods, and by generating rational segments as straight lines or arches. The lengths of the segments, as well as the perpendicular distance of straight lines that connect the start and end points of the segments to the segments, are calculated in order to re-build the profile curves (Figure 2).

The surface is generated via the loft command, which is able to fit a surface through selected profile curves that define the surface shape using Rhino geometric modelling software. A NURBS surface can be described by the polynomials of two independent parameters called the U and V values, which are the divisions of the surface in the x and y directions. It is necessary to introduce a grid for the parcelling of the masterplan and for the major roads connecting the masterplan area to other cities. A grid and a sub-grid, driven by the geometric properties of the surface, as well as main roads in the north-south direction to be used as the major transportation spine, are integrated into the system (Figure 3). By increasing or decreasing the number of grid elements of the surface, the parcel sizes and shapes can be altered. Thus, various options for the parcelling of the masterplan are generated.

The natural formations on the existing land, which appear as gaps in the forests, lead to the investigation of soil erosion in natural processes. Soil erosion occurs as a rule-based system in nature and obtains characteristics related to the directionality, linearity and specific ratios for length-width. Some rules are specified towards the formation of building geometries. The rules can be specified as follows, in which w and l represent the width and length of the building, respectively:

- *rule 1:* w< l/5.
- *rule 2:* building positioning / north-south.
- *rule 3:*building boundary / offset by 5 meters inwards from the parcels.

Although the geometry of the masterplan responds to the site conditions, the parcels are generated by avoiding hierarchy and by aiming to democratize the use of parcels. Public, private and mixed-use buildings are introduced as different building types that create a continuous skyline that can be altered based on the design intent and density requirements.

### 2.3. Optimization process

Design is considered an optimization process. It is critical to generate iterations/options for design development by eliminating immature solutions (von Bülow, 2007). Many of the optimization processes used in engineering disciplines are adopted from a natural phenomenon, such as genetic algorithms (GA). Stochastic methods would be suitable for undertaking complex tasks; specifically the GA, which is based on analogies in biological genetics (Dimcic 2011; Turrin et. al. 2012; Kawamura and Ohmori, 2001; von Bülow, 2008; von Bülow et. al. 2010). Optimal space is a universal mathematical object ruled by natural laws (Passino, 2005). Classical optimization methods are not sufficient for producing a variety of solutions. Evolutionary algorithms, however, can produce various solutions by working on multi-objectives. The design variables, objective functions and constraints are the important domains of optimization that need to be specified for optimization calculations. The design variables are those that can be changed to find an optimal solution. The goal of the design is the objective function, which is a mathematical definition of a term and mainly describes a minimization.

Galapagos is an optimization engine on Rhino Grasshopper based on an evolutionary solver, GA. Evolution starts from a population by generating randomized individuals; each iteration is called a generation. Fitness is the objective function of the optimization problem. The generation process is carried out until the fixed number of generations is reached. The fitness score represents the ability of an individual to compete. Evolutionary algorithms do not guarantee a solution nor is there a perfect solution. Every solution has drawback and limitations. If a predefined sufficient value is not specified, the process may run on indefinitely. Evolutionary algorithms have strong benefits, such as their flexibility at being able to handle a variety of problems. Additionally, because the run-time process is progressive, intermediate answers can be given. The variables, which are referred to as genes in evolutionary computing, are the values that can be changed. By using different combination of genes, better or worse results can be achieved. Every combination of genes results in a particular fitness. The initial step for the solver is to populate the model space with a random collection of individuals, or so-called genomes. They can be also called chromosomes. A genome is a specific value for each gene and the algorithms defines how fit every genome is. While the selection process aims to find the survival of the fittest, coalescence represents the gene combination. Breeding or coupling is the process of finding mates. After being elected to mate by the selection algorithm, the individual needs to pick a mate from the population. Selection occurs through genomic distance. To select individuals that are not too close or too far, the in-breeding factor can be determined in the Galapagos program. Because selection, coupling and coalescence have a tendency to *reduce* the bio-diversity of a population, the only mechanism that can introduce diversity is mutation, which introduces random modifications. A population of candidate solutions is generated in the solver (Galapagos, 2016).

A Grasshopper code for the parametric model is created for the generation of the computational geometry, including the parcels. The profile curves based on the site input are assigned to the loft command to generate the computational surface. Then the lofted surface is divided into sub-surfaces, which can be altered based on the number slider that controls the U and V values of the NURBS surface, assigned as 20

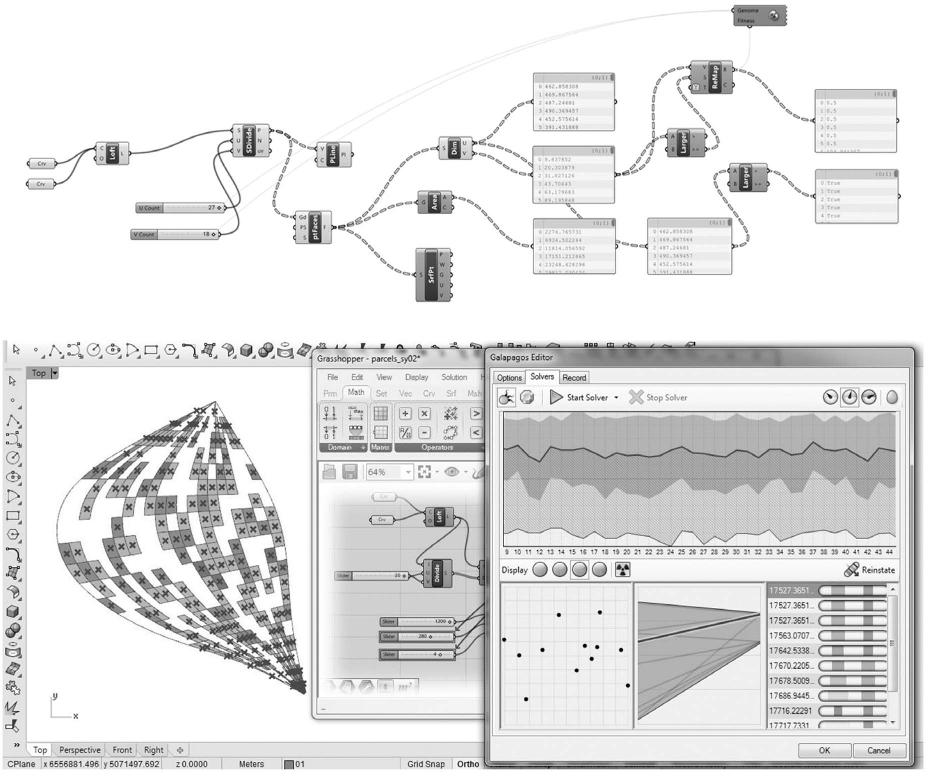


***Figure 4.*** *Grasshopper definition towards finding the fittest solution by operating the evolutionary solver: Parcels are indicated as the built-parcels and the remaining ones are considered as green areas.*

in the model. The subdivided surfaces are extracted as items that retrieve specific items from a list. The items are connected to the random button, which can generate a list of pseudo random numbers. It obtains three variables called Range(R), Number (N) and Seed (S). While R represents the domain of a random numeric range, N represents the number of random values and S the seed of a random engine. The number slider ranges are indicated as follows:

R=0-1200
N=250-300
S=1-5

The areas of the items, which represent the parcels, can be calculated. A list is generated through the panel for text. While the parcels generated by the code represent the built-parcels, the remaining areas represent green areas. By altering the parameters, different variations in parcel layout, and therefore different distributions of the green areas and built parcels, are created. Due to the necessity of reducing computing power, the model is simplified by excluding roads in the optimization process.

For running the evolutionary solver in Galapagos, two input values need to be specified: the Genome and the Fitness. The Genome represents the genes and the variables to be altered while the fitness represents the objective function that the system aims to achieve through the process. The genome is connected to the N and S values of the random button (Figure 4). Fitness is selected by minimizing total built areas so that the algorithm finds the best fit solution by increasing green areas during the optimization process. The runtime is not restricted. Below are the initial settings used in the optimization process:

**Maximum Stagnant: 50**
**Population: 50**
**Initial Boost: 2x**
**Maintain: 5%**
**Inbreeding: + 75%**

## 3. Results

The optimization is based on minimizing the total built area so that a maximum gain in the distribution of the green areas is achieved. Based on the optimization, the iterations (I) are analysed. F, N, values, green areas and the green area ratios, which indicate the ratio of green areas to the total area, are specified (Table 1). The total area of the masterplan site is 7,158,509.02 sqm. The fittest solution (I-1) is achieved for N=280 and S=4, with the fitness value (F) of 17,527.3651 by reaching the global maxima, of which the total cumulative built area is 4,907,662.24 sqm. The least fit solution (I-2) achieved through the computation of N= 276, S=1, and F= 19,228.3056, of which total cumulative built area is 5,307,012.36 sqm. Through the computation of various other solutions, I-3 and I-4 are generated in between the fittest and least fit solution. It has been observed that the system did not generate any solutions by using the maximum or minimum values for the variables, in which N= 250 or 300, and S=0 or 5 (I-5, I-6), because the algorithm only works by taking some portions of the variables, the genes, as a result of an operation of the GA's in which all the genes are incorporated through crossover. One unexpected outcome of the optimization is that although the I-3 and I-4 obtain a smaller built parcel area, they was not considered the most fit solutions following the computation of optimization. The interpretation is that the I-1 obtains one of the better combination of genes (Figure 5).

***Table 1.*** *I-1 and I-2 are the fittest and least fit solutions offered by the evolutionary solver.*

| | F | N | S | built parcels (sqm) | green areas (sqm) | Ratio: green areas to the total area |
|---|---|---|---|---|---|---|
| I-1 | 17.527,3651 | 280 | 4 | 4.907.662,24 | 2.250.846,78 | 31,44 |
| I-2 | 19.228,3056 | 276 | 1 | 5.307.012,36 | 1.851.496,66 | 25,86 |
| I-3 | 17.686,9445 | 261 | 3 | 4.616.292,52 | 2.542.216,5 | 35,51 |
| I-4 | 18.111,2110 | 262 | 2 | 4.745.137,28 | 2.413.371,74 | 33,71 |
| I-5 | none | 300 | 5 | 5.463.710,51 | 1.694.798,51 | 23,68 |
| I-6 | none | 250 | 0 | 4.484.068,47 | 2.674.440,55 | 37,36 |

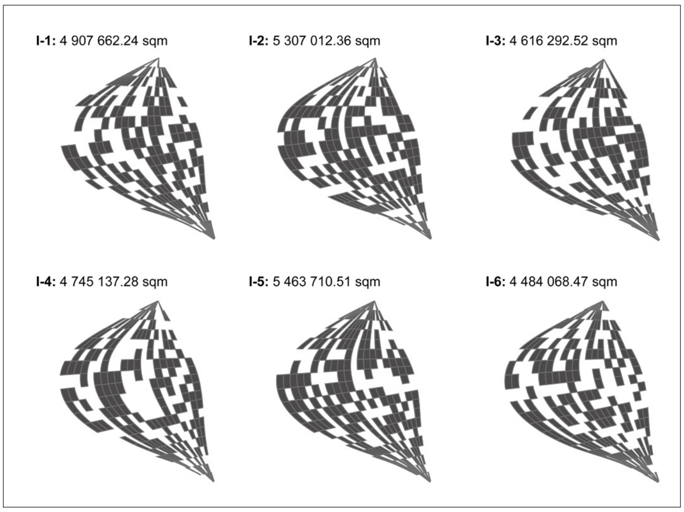


***Figure 5.*** *Parcel distribution of different iterations, representing the built parcels. The rest remains as green.*

The results underline the fact that although the optimization process driven by evolutionary algorithms assists users by creating iterations and a variety of options, the system cannot choose which one is the best solution depending on various design issues. The option developed further for the masterplan design is based on the analysis of the solution space generated by the optimization process combined with the experience, knowledge and intuitiveness of the designer / architect. Some parcels are merged into larger fields on the final version of the masterplan in order to accommodate land for forests and urban agriculture.

Landscape becomes an integral part of the proposed masterplan and a sufficient amount of green areas must be created to generate a self-sustained system by using local resources, generating its own energy and managing waste materials. A self-sustained ecological system should have a balanced distribution of green areas. The proposed masterplan introduces land portions, which are set aside for forests, urban agricultural land, and parks (Table 2). The largest portion of the landscape is taken up by forest in order to maintain a natural eco-system. The purpose of the proposed urban agriculture land is to benefit the food supply. Additionally, a sufficient amount of parks are introduced as an output (Figure 6).

***Table 2.*** *Land use distribution of the masterplan.*

| Total green areas | Forest land | Urban agriculture land | Parks |
|---|---|---|---|
| 4 545 621, 75 sqm | 1 293 967 sqm | 517 497 sqm | 392 046 sqm |
| 100% | 28.47% | 11.38% | 8.62% |

Proposed massing creates a seam-

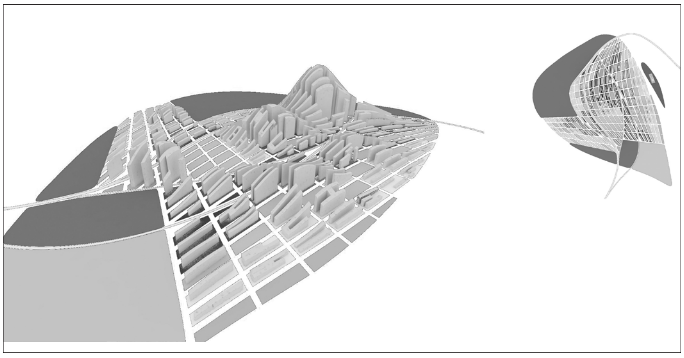

***Figure 6.*** *Outcome of the masterplan.*

less skyline that reaches up to 410 m. The peaks in the masterplan skyline are high rise buildings that offer high density urban settlement, which is inevitable in order to maintain the highest portion of forests and other green areas in the built environment. The system offers 9,669,103 sqm of a built environment, from mid- to high-density settlements, in order to accommodate a minimum of 340,000 inhabitants who require approximately 6,800,000 sqm / 20 sqm per person as requested by the design brief.

## 4. Concluding remarks

The concept of landscape urbanism is based on prioritizing landscape design in urban planning. The design of buildings is considered an outcome of initial landscape decisions. Digital design techniques influence all fields of disciplines. CD enables us to establish design systems using algorithmic logic in which parameters, rules and relationships are defined. Because of the necessity for a method that can integrate issues related to form generation and finding the optimal green area distribution of a masterplan, a parametric landscape urbanism method has been developed. By applying the procedures in the methodology, a solution space is created that consists of iterations through the optimization process. The green area ratios are then calculated.

The results have proven that the algorithmic approach in the design and optimization processes enable to work with iterations for finding optimal solutions by comparing different alternatives. Although evolutionary algorithms enable us to create a solution space, architects, designers and landscape architects need to make their decisions through comprehensive assessments concerning various design issues and intents for choosing the best solution unless there is an objective design goal that can be computed through the optimization process. The proposed method uses an algorithmic approach for a relevant design problem, which is important when creating a connection between the research undertaken in the field of CD and the practice in order to investigate the capabilities of the current CD tools and enhance them.

The scheme proposes certain percentages for green area distribution. However, these figures can be altered by maintaining systematic design principles and unity.

The proposed method creates a self-sustained ecological system by creating a balanced distribution of green areas.

Although the proposed method offers some indication related to a feasible distribution of the buildings on site, the model can easily be adapted to different possibilities through the parametric model. Because of the optimal geometry and size of the parcels, different building types can be implemented and various iterations can be created by using different parameters. The parcel sizes, as well as the building geometries, can be re-configured based on increasing or decreasing the density of urban settlement.

Although the method has been tested on a specific site domain in Europe given by the design brief, it can be implemented on other site domains and optimized for different problems by re-defining the parameters.

For future research, more studies should be undertaken to integrate the sub-systems into the masterplan including the infrastructure, water and waste management of the landscape. It is possible to assess the NURBS-based surface model of the landscape as a 3D terrain by integrating issues related to the ground. Additionally, a multi-objective optimization process can be developed towards the solution of comprehensive design issues in landscape architecture, such as the climate, topography, distribution of plant morphologies and soil types.

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