Landscape Design Methodology: Pattern Formation Through the Use of Cellular Automata

Marcel Bilurbina[1], Sergi Abellan[1], Marilena Christodoulou[1]

[1]AELAND, Barcelona/Spain · mbilurbina@aeland.net

Abstract: The purpose of this study is the development of a landscape design methodology based on the use of a Cellular Automata (CA) algorithm in order to introduce the plant-plant interaction factor in the plantation design of a site. This design methodology introduces the relations between neighbouring individuals of different species as parameters of the project. These parameters are codified in order to define the Cellular Automata rules. Parameters related to the growing and morphologic characteristics of the species but also programmatic and aesthetics parameters of the project may be introduced as rules that influence the behaviour of the CA algorithm.

The algorithm developed it is called NNB-CA (Natural Neighbouring Behaviour Cellular Automata) and it is based on the original John Conway's "Game of Life" CA. The design methodology takes in account site conditions and is developed in 2 phases. In the first one, starting with a list of species, a preselection of them is done taking into account parameters of the site and defines which species are able to populate on each area of the discretized site. In the second phase, the CA algorithm is run applying the relational rules with the selected species. This iterative process is applied until it reaches to an equilibrium state.

Rules related to the competition between species according to their growing characteristics are studied comparing an analog/natural evolutive process using rapid development plants and the correspondent digital process that simulates the analog one.

Keywords: Cellular automaton, digital landscape architecture, algorithmic design, community dynamics, digital ecosystem

1 Introduction

Plants, and in general living organisms, can be considered as systems that can obtain their complex forms and patterns of behaviour by interacting in space and time within their individual components (WEINSTOCK 2010) These complex systems, live under the laws of self-organization. The agents of these systems, by following simple local rules, interact with each other and with their collective behaviour, they are able to adapt to the environment and evolve (JOHNSON 2002). Evidently, the growth of these systems and in this case, the growth of the plants, depends on different factors. The first one, of course, is the climate, although no less important are the substrate on which it will develop, the availability of nutrients or, in the case of gardens or parks, the irrigation.

However, a factor also very important, is the competition between the different specimens or between different species. For example, the shadow projected by a large tree will prevent many species from developing, which taking into account only the rest of the factors they could live there. At the same time a plant that has been growing in one place for a while, may end up being displaced by another; either because of its faster development, or because it alters the conditions of the habitat, competing more aggressively for resources or directly suffocating it with its growth.

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While planning the planting of a green space, the aforementioned factors are taken into account, even though the role of competition between species is solved vaguely. An approximate future development diameter is established for the trees, some zones with shrubs, perennial or caespitose plants. This zoning is done randomly, based on design criteria that avoid considering the way that different species interact with each other and that are based on the maintenance that each species will remain in place.
The design methodology proposed, tries to solve the organization of the species considering the relation of each individual with its closest neighbours. The relation between each species and the others is established, parameterized and codified comparing its growing and morphologic characteristics. After that, an iterative process runs that starts defining a matrix of cells/individuals occupying the area to plant and associating one species to each cell/individual in a random way.

Once the first population is defined, the number of immediate neighbours of each cell is being recursively calculated and replaced by a new species depending on its neighbours.

This iterative process is applied until it reaches to an equilibrium state, and the state/species of each cell becomes stable. The algorithm applied is an implementation of the "Game of Life" Cellular Automaton (CA) defined by John Horton Conway where rules are based on the Natural Neighbouring Behaviour (NNB-CA) of the species.

2 Natural Neighbouring Behaviour Cellular Automaton – Design Methodology

The design methodology uses Processing, an open source graphical library and IDE that uses Java language, as a main engine to run the Cellular Automata, as well as CAD and GIS software to extract data from the site.

2.1 Steps of the Design Process

2.1.1 Initial Selection of Species and Evaluation According to the Site Evaluation Parameters

A list with the desired species to work with is defined and each species is evaluated according to the different parameters of the site analysed.

The site parameters analysed may vary from topographic (altitude, slope, orientation, curvature, etc), climatic (sun radiation, wind, etc), soil characteristics, geometric (proximity to some place, etc) or any other data that can be parameterised.

An .XLS file is created introducing the evaluation/characteristics of each species related to each of the parameters analysed. This file is imported as XML (Extensible Mark-up Language) file in order to have access to this data. Data from site is acquired using CAD / GIS software and it starts with the discretisation of the site. The site is divided in an array of square Cells (the size of the cells is the same for the whole design process). Each Cell is then evaluated according to the same analysed parameter and a numerical value is associated to each cell for each parameter (Figure 1). The numerical values related to one parameter are called "layer of information". An .XML file is created for each layer of information.

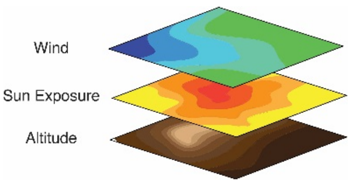


Fig. 1:
Example: Site evaluation; Layer of information

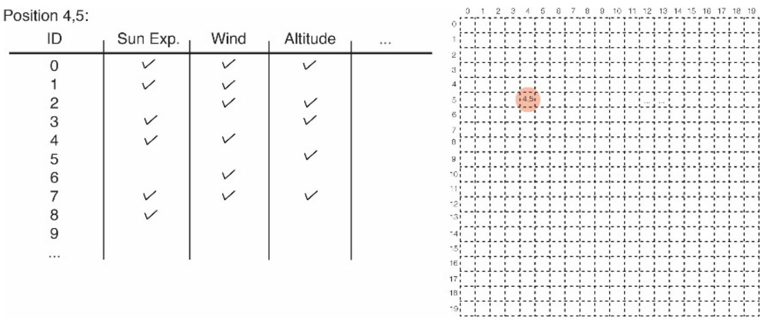
2.1.2 Preselection of Species According to the Parameters Analysed

Site is imported to Processing in SVG file format and subdivided in square Cells, with the same resolution that the analysed site files.

The layers of data analysis are imported to Processing parsing the different XML files Cells are fulfilled with species following the next process:

- Per each Cell and per each Layer of information: check which species fulfil the values of all the analysed parameters (Figure 2).
- Fulfil each Cell with a list of the species that fits with the analysed parameters.

Resulting matrix is an array of lists of species, one list per cell, where each cell has a dimension that corresponds to the number of species that fits with the whole analysed parameters.


Position 4,5:

ID	Sun Exp.	Wind	Altitude	...
0	✓	✓	✓	
1	✓	✓		
2		✓	✓	
3	✓		✓	
4	✓	✓		
5			✓	
6		✓		
7	✓	✓	✓	
8	✓			
9				
...				

Fig. 2: Example: Preselection of species

2.1.3 CA Rules Definition

CA are algorithmic models that uses computation to iterate on very simple rules. While iterating, these simple rules can create complex, emergent phenomena through the interaction between agents as they evolve over time. The NNB-CA is based on the Conway's "Game of Life" CA algorithm.

The main goal of the NNB-CA implementation in the design methodology is to introduce the relation between neighbouring individuals as a project strategy. The relation between each species and the others is established, parameterized and codified according to different relational parameters, defining the behaviour rules of the CA (Figure 3).

Features of the Natural Neighbouring Behaviour CA vs CA "Game of Life".

	GOL-CA	NNB-CA
Discretization:	square cells	square cells
Neighbours:	8	8
States:	2	As many as species have been preselected
Values:	0 (dead) / 1 (alive)	ID correspondent to the species

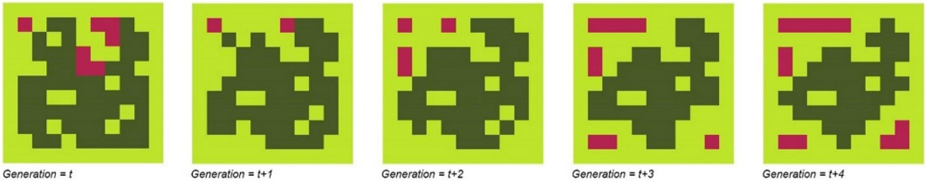


Fig. 3: NNB-CA. Evolution in a 11x11 cells site, with 3 states (species)

Relational parameters implemented in the NNB-CA refer to the growing characteristics and species competition, to aesthetical criteria and to programmatic project needs.

Rules based on the **competition** between individuals are established, for example, evaluating the *height of the species and their horizontal development because there are species that extend* as ground covers until they do not find a higher species or another competitive creeping species that limits their development. Another example are large groups of certain species that can be more subjected to plagues caused by overcrowding than small groups, therefore a limitation of the number of individuals in each group is established to avoid these problems. Rules based on **programmatic** or **aesthetic** criteria may also be applied, as for example if it is preferable to have an aromatic specie close to a path or if two species do not fit side by side in a colour scheme, but match if there is another specie between them.
Other rules based on the relative position between species may be defined following the same logics in order to introduce the effect of the shadow between species, depending on its height and orientation.

2.1.4 CA Implementation

Initial random population. Having the site divided in cells and a list of possible species per each cell according to the pre-selection, an initial random population is created. Each cell has one only random species associated.

Iterative process. The following procedure runs, following the next steps:

- Calculate the number of immediate neighbours of each species each cell has.
- Rules application. Each cell is evaluated according to the immediate neighbours following the defined rules. After this evaluation Cells may vary their state or not.
- Generations. Each evaluation process for the whole array of cells corresponds to a new generation and its executed iteratively.
- Iteration condition. This iterative process is applied until it reaches to an equilibrium state, and the state/species of each cell doesn't change.

Equilibrium state. When the iterative process becomes invariant all the conditions established by the substitution rules are true. The equilibrium state corresponds to the most efficient organization in terms of plant-plant interaction.

2.1.5 Output Result

The final distribution of species fulfils all the defined conditions in both parts of the design process, when it fits with the analyzed conditions of the site, when the relation between species is stable according to its natural behavior and when it fits to the aesthetics and the introduced programmatic neighbouring rules.

3 Analog/Digital Models Evaluation

The study of the codification of the relation between species according to its growing characteristics is carried out comparing an analog/natural evolutive process using rapid development plants and the correspondent digital process that simulates the analog one.

By studying the growth of three floating water plants the aim is to prove that the interaction of the 3 species generates a recognizable pattern (CAMAZINE, DENEUBOURGH, FRANKS, SNEYD, THERAULA & BONABEAU 2001), that the difference of the growing characteristics between species can be codified and parameterized digitally and that the pattern of the plants that has been generated naturally coincides with the digital simulation implemented using the Cellular Automata algorithm.

The analog/digital comparison seeks to demonstrate if it is possible to establish a digital model that is assimilable to the development of a series of species. To evaluate this, we propose the use of three species (Figure 4) of floating plants of rapid development, and the establishment in parallel of a digital model with a series of simple rules in the relation plant-plant and plant-environment (Higgins & Richardson 1996).

Fig. 4: The three species of the analog experiment: Azlla caroliniana, Lemna minor, Spirodela polyrrhiza

The conditional rules in the CA are established in relation to the competition for the space and form of development of these species, considering that all three present a similar growth rate and that is mainly influenced by the available space and their capacity to replace or not the specimens that are around each individual. The three species used are *Lemna minor*, *Azolla caroliniana* and *Spirodela polyrrhiza*, all three showing a size from 0,5 to 1cm per specimen. The installation is formed by three containers with the same characteristics; square containers with dimensions of 40 × 40 cm (Figure 5). The density of the population is 100 % since the beginning of the experiment, so that the relationships between the species can be directly assessed by inter and intraspecific competition. The initial proportion of individuals of each species is of a 1/3 and these are introduced randomly, in the same way that the digital model starts from a random disposition. The culture conditions for the three containers are identical, so that the obtained results from the three samples are equally representative.

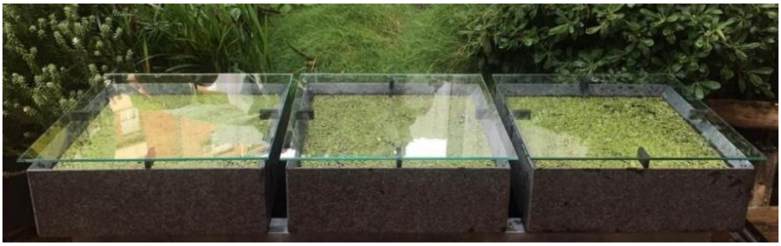


Fig. 5: Image of the analog experiment

The digital model has been implemented with Processing after observing their behaviour. For example, *Azolla caroliniana* tends to form large carpets of individuals that remain attached between them, as the plant grows and multiplies itself in a dichotomous way. *Lemna minor* multiplies itself by scission of the individuals, therefore the group has the tendency to be laxer, giving also the possibility to the plants to fill the spaces between the other species. *Spirodela polyrrhiza* multiplies itself also by scission, but the individuals, a part from being larger, are more sessile than *Lemna* (BOWN 2000).

Relations between the three species were considered in order to define the rules. Azolla tends to dominate over *Lemna* and to occupy its place. Also, when Azolla grows forming large groups, the intraspecific competition, particularly in environments with scarce phosphorus like the experiment, tends to leave empty spaces that can be occupied by other species, especially by *Lemna. Spirodela* is little affectedly the development of *Azolla* and even less from *Lemna*, but requires more nutrients that the others, specially than *Azolla* that can fix nitrogen from the atmosphere because its symbiosis with Anabaena. Therefore, the population of *Spirodela* is limited also by intraspecific competition. Lemna is the more ubiquitous specie therefore can occupy large patches and is less affected than the others by intraspecific competition.

The relation between species has been codified, defining the following rules:

- If *Azolla* has more than 6 neighbours *Azolla* >> *Azolla* becomes *Lemna*, else stays *Azolla.*
- If *Spirodela* has more than 4 neighbours *Spirodela* >> *Spirodela* becomes *Lemna*, else stays *Lemna*.
- If *Spirodela* has more than 5 neighbours *Azolla* >> *Spirodela* becomes *Azolla*, else stays *Spirodela*.

In order to obtain conclusions from the analog experiment the images have been digitally processed, grouping the different species and enabling the comparison with the digital model (Figure 6, 7).

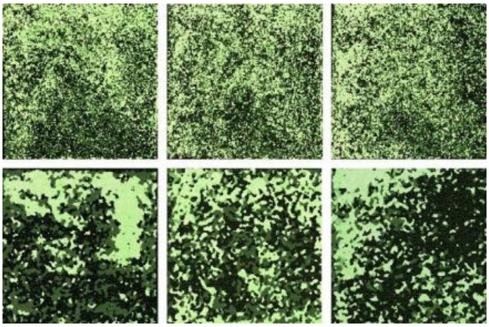


Fig. 6:
Image from the series of the analogical experiment, the upper images are from the beginning of the experiment, the lower are the aggrupation formed 2 months later

Fig. 7:
Digital simulation (Processing Java). From left to right: 1st random generation, 2nd generation and 30th generation.

4 NNB-CA Case Study

The following case study shows the implementation of the design methodology where the Natural Neighbouring Behaviour CA it has been implemented. Only relational rules have been introduced, considering that the site parameters are the same for all the individuals. Pre-existing species have been loaded with the SVG site file and are coloured in light and dark green in the Processing interface. Both species interact with the new species but do not change because the goal it is to get the right new plantation adapted to the pre-existing species.

In this habitat there are two principal species, the rosemary and the juniper. The objectives of the new plantation are mainly to preserve the existing vegetation, as well as include new species that not outcompete with them, but are useful to add interest to the garden, and covering for the altered soil. Also, apart from these premises, some existing species like the junipers are very slow growers and difficult to settle after the plantation.

The plantation consists of five species, well adapted to grow in these conditions. These species show a faster growth rate than the existing species but also have some characteristics to be considered. The proposed species are prostrate rosemary, westringia, pistace, artemisia and sage. Artemisia and sage, for example are plants that will lose a lot of leaves in winter, and need to be pruned to a low height leaving empty spaces in the garden, therefor, in order to maintain the year-round interest of the garden, it will be preferably to do not use these species side by side.

On the other hand, the sage competes a lot with the preexisting rosemary as it can overgrow them, therefore it is not advisable that it is planted nearby. Artemisia summer growth extends so much that can compete with the junipers, therefore it is also advisable that the artemisia is not planted near the existing junipers.

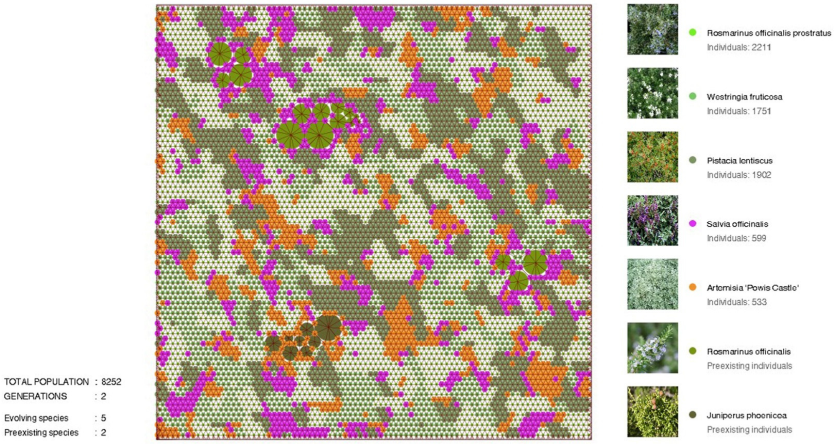


Fig. 8: Natural Neighbouring Behaviour CA

The pereexisting species (Figure 8) are *Rosmarinus officinalis* (coloured in light green in the Processing interface), *Juniperus phoenicea* (couloured in dark green in the Processing interface).

The new plantation species (Figure 9, 10) are prostrate rosemary (*Rosmarinus officinalis prostratus*), westringia (*Westringia fruticosa*), pistace (*Pistacia lentiscus*), sage (*Salvia officinalis*), artemisia (*Artemisia* 'Powis Castle')

he relation between species has been codified defining some rules. For example, next to pre-existing *Rosmarinus officinalis* only *Artemisia* plants can be planted, next to pre-existing *Juniperus phoenicea* only *Salvia* plants can be planted, *artemisia* and *Salvia* cannot be planted side by side while the rest of the species have a relation of simple dominance between them: One species is substituted by a second one if the number of neighbours of the second one is bigger than the number of neighbours of the first one.

5 Conclusions

Having started the analog experiment from 3 different random initial situations with the same environmental conditions, we were able to verify the formation of the same pattern in the three containers. Having them growing with the same environmental conditions, allows us to determine a competition relationship that could be established.

In the same way, the digital model can reproduce a similar pattern to the one generated in the analog. Taking into account that the development of the different species is determined primarily by the available nutrient resource, a plant that cannot grow, cannot be able to compete with other species. In the experiment, high-competitive species like *Azolla* are deprived of phosphorus to control their development (RANKER & HAUFLER 2008), and to assure a balanced competitive relation with the other species. The parameterization of competitivity between species depends, on a high level, on the requirements of each of them. However, although these requirements are different between species, it is possible to parameterize this competitivity when the requirements are proportionate and consequently quantifiable between them. On the other hand, in the landscape design field, species from the same habitat or that are originally from analogous habitats with similar climate, insolation and soil conditions, are equiparable in their needs. Therefore, a peer to peer relationship between species could be established, leaving only competitive (or aesthetic) parameters as determinant to define which species fits which place. In this way, the parameterization of the relation between species using the NNB-CA method is useful in order to define plantation projects, by taking into account the species that are more suitable for the varied conditions of a determinate place, using firstly the analyzed data of the site and applying competition and/or aesthetic parameters.

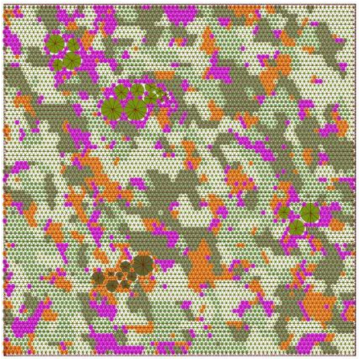


Fig. 9: NNB-CA, Processing implementation, 2nd generation

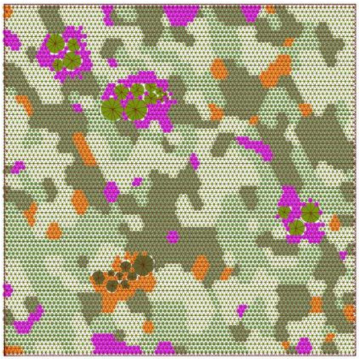


Fig. 10: NNB-CA, Processing implementation, 15th generation

Sustainability is, in the same way, improved, as position of the species is defined by controlled parameters based in the most propitious place for each species and the relation between them. Sustainability can also be improved, even with rules based on the relative position between species, which makes it possible to take into account effects like the projected shadow of trees or shrubs, giving the possibility altogether to minimize the irrigation and maintenance needs.

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