Multi-Criteria Agent Based Systems

Generation of circulations through local decisions

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This study explores to what extent Agent Based Systems (ABS) can handle multi-criteria optimization problems. The implementation of ABS in the field of optimization has limitations to address multiple criteria in a continuous generation process due to ABS usually merge the perceived information in a single response. To address this limitation, we increase the responsiveness of the systems through a multiple production approach. This approach breaks down the problem into two parts: the configuration through the interactions of the agents, and the overall performance through their local decisions. The method is tested in a case study of the network circulations of a park, optimizing the slope, views and sun. Performance and differentiation capabilities are evaluated in populations generated in two different scenarios. Data analysis methods verify the effectiveness of the algorithm and quantify the influence of each parameter on the final results.

INTRODUCTION

This study explores to what extent Agent Based Systems (ABS) can handle multi-criteria optimization problems. The ABS are decentralized artificial intelligence of multitude of entities that demonstrate collective behavior through local decisions (Weiss, 1999). The denomination of these systems has been discussed by many authors (Pantazis & Gerber, 2018). However, for the purposes of this study they will be designated as ABS to synthesize these models. On the other hand, Multi-criteria Optimization (MCO) seeks to satisfy multiple potentially conflicting objectives (Haymaker, et al., 2018). This method is focused on representing the trade-offs rather than finding a unique solution. This study explores the combination of both approaches in a single iterative design process (Aish & Joyce., 2012).

In the last 10 years, ABS has been implemented in six fields related to architecture: Crowd simulation, program distribution, context interaction, materials, fabrication, and robotics (Figure 1). Chen (2008) studies the simulation of crowds of occupants in the space. While Hao Hua & Ting-Li Jia (2010) addresses the distribution of the program, Puusepp (2014) the circulation system, and Li Biao et al (2008) the interaction of the program configurations with the environment. Taron (2012) studies formal exploration and Tsiliakos (2012) form optimization both through an iterative process of addition and subtraction of material. In terms of Fabrication, Schwinn et al (2014) apply ABS for calibration of parts, and Gerber & Pantazis (2016) for facade generative systems. Finally, in

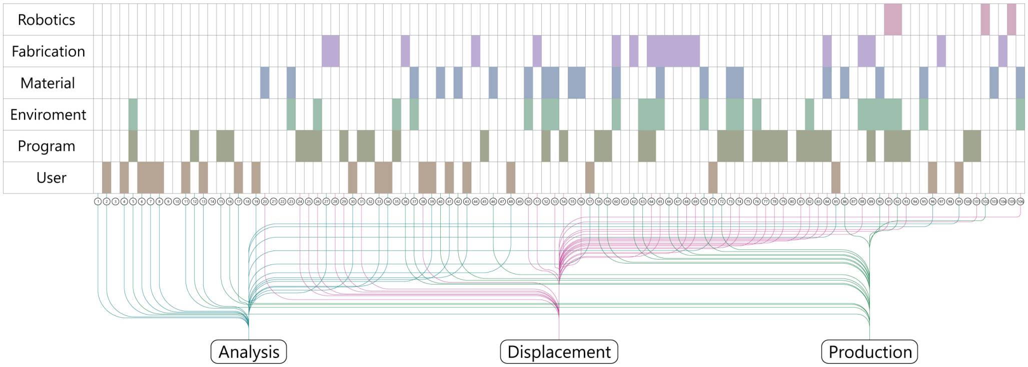


Figure 1
Application fields and generation typologies in ABS in the last 10 years.

the field of robotics, Pietri & Erioli (2017) implement ABS for controlling autonomous entities for the manufacturing, and Melenbrink et al (2017) for the configuration of lightweight installations.

In parallel, a distinction must be made between analysis and generation models. The former quantify some aspect of an environment through interaction with the agent. The majority of this typology consists of simulations of crowds of people to assess the intensity of circulation use in urban environments or shopping centers. Although there are cases where transformations occur from the results of the analysis (Lim, 2011), the influence of ABS on the design requires interpretation.

In the models of generation the agents constitute the form. There are two types of models depending on the action of the agent in each iteration. In iterative displacement models, the position of the agent changes in each iteration, seeking a balance based on the optimization of an objective. Therefore, the result is the last position of the agents once the development of the model has been completed. An example of this typology is the organization of complex programs by Hao Hua & Ting-Li Jia (2010). In iterative production, the agents add one or more new agents to the system in each iteration and, consequently, the final result consists of all the positions of each agent throughout the process. An example these production models are those that interpolate the paths of the agents to arrive at a result (Alborghetti & Erioli, 2014) and those of material addition. When an agent produces more than one entity per iteration it is called "Multiple", which increases the complexity of the model. For example, Lopez and Gerber (2014) generate urban configurations by implementing bifurcations while reading the context and addressing multiple objectives.

The latest examples of ABS in architecture are found in Manufacturing and Robotics, far from the efforts in developing complex programs due to their scale. While there are examples of application of ABS in the program configuration (Taron & Parker, 2013), current developments are not focused on continuous generation and they allude to post processes to address multiple objectives. This is partially due to the ability of ABS to facilitate the exchange of information between agents seeking a unique response for multiple requirements and at the same time avoiding hierarchical structures (Parascho et al., 2013).

The expected result of this study is the definition of a theoretical framework for a continuous process of generation and optimization. For this purpose, a case study about the generation of the circulation network of a park allows to explore the effectiveness of model of multiple production by iteration, evaluate the ability of ABS to satisfy multiple criteria, as well as to generate differentiated results.

Finally, the article is structured in six sections: the description of the objectives of the system, the approach to read the context, the internal mechanics of the system, the generation of results populations, the validation of the results, and the final discussion.

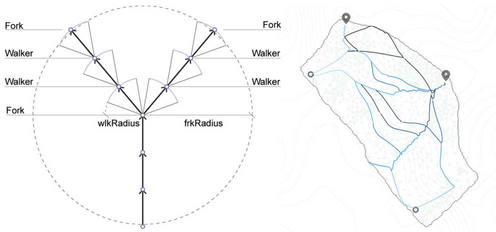


Figure 2
Walker and fork agents to the left, and park access (circles) and targets points (markers) to the right

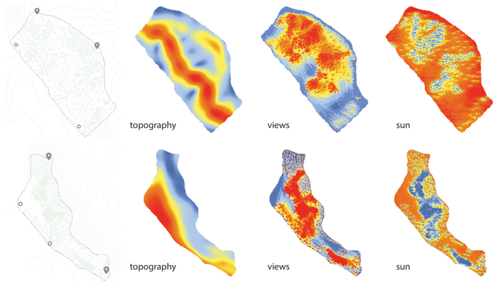


Figure 3
Evaluation of the three criteria

METHODOLOGY

The case study is the circulation of a park intended as a system of routes and bifurcations. The algorithm implemented in Python within the Rhinoceros / Grasshopper environment consists of the classes Fork and Walker, and a third one that coordinates their interactions. While the agent Walker travels across the park through a sequence of steps, the agent Fork bifurcates through the production of multiple Walkers. The agent system works through the definition of access and target points. The task of the algorithm is to generate a network of circulation in the process of connecting them (Figure 2). For this purpose, a Fork agent in each access produces Walker agents in the direction of the objectives. They make a journey to reach a certain distance from their origin and produce a new Fork. This process iterates until the connections with the target points are made.

The circulation is intended to minimize intervention in the field, using the existing factors to determine the configuration. In this way, circulation is defined by topography, views and sunlight. The agents seek to optimize these aspects: minimizing the slope, maximizing the visual angle and maximizing the shadow in each position. Therefore, the system consists of a generation and optimization process together. The approach to the design problem is through a series of discrete and informed decisions that gradually shape the configuration of the result. The decision-making process of the agents involves reconciling the optimization and generation objectives in parallel throughout a continuous process.

Context

There are two scenarios to implement the algorithm (Figure 3): the first is called Peña Blanca (PB) and the second Laguna Verde (LV) both allocated in the center of Chile. Two 5 m2 meshes with 19,478 reading points for PB and 9,405 for LV evaluate three aspects. The angle between the normal of each point and a horizontal line measures the slope of the topography. An isovist diagram that projects 20 horizontal lines in 360° measures the depth of the visual field. A simulation of solar radiation maps the obstructions produced by vegetation in 32 point-in-time along the year. The values for the three aspects per point are normalized through the minimum and maximum of the two locations. Finally, the weighting factors 'topoRatio', 'visionRatio' and 'solarRatio' allow prioritizing the influence of the criteria.

To read the criteria of line of sight and sunlight, the agent looks for the corners of the face of its current position and interpolates the reading of the three corners for each criterion as a function of the distance. Regarding the topography, in each iteration the agent evaluates the angle between the horizontal and the potential line of positioning. The values of the three criteria are normalized in a domain from 1 to 100 through the limits obtained through the total reading of the context.

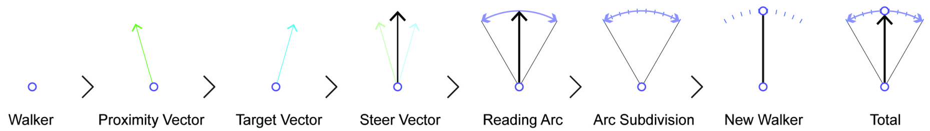


Figure 4
Generation sequence of the walker agent

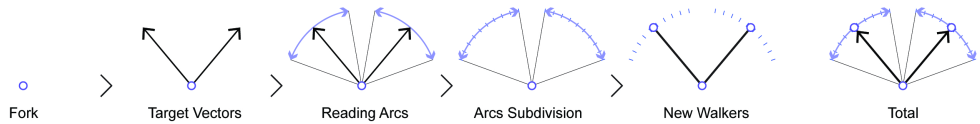


Figure 5
Generation sequence of the Fork agent

Walker
The agent Walker (Figure 4) generates a section of the route based on the reading of the environment and the awareness of its neighbors. First, the Steer Vector is determined by averaging the Target and Proximity Vector. Then, the Steer Vector place the reading arc and the parameter "arcAngleWlk" determines its extension. Finally, the arc is divided into points depending on the resolution of the mesh. The point with the highest performance value generates the next agent.

Fork
The agent Fork (Figure 5) generates a bifurcation through the generation of a Walker towards each target point. A target vector points towards each objective. The vectors place Reading Arcs that extend according to the "arcAngleFrk" parameter. The arcs are subdivided into points. Those points with the highest performance value generate the new Walkers.

Fork agents drive the behavior of their Walkers. They are classified in internal and external Walkers. While the internals share the fork of origin, and externals do not. This difference influences the way Walker get the Proximity Vector. The agent Fork has a radius of influence determined by the input "frkRadius" that controls the distance a Walker must move away from its origin Fork to produce a new Fork, and the area in which the Walkers detect their neighbors.

Proximity Criteria
The proximity criteria control the distance and connections between Walkers through the Proximity Vector. There are two criteria: attraction towards external Walkers and repulsion from internal ones. The attraction facilitates connections in the circulation promoting the convergence with external Walkers. The repulsion keeps the distance from internal Walkers to avoid overlapping and crossing paths. The average of the vectors from each internal and external Walker defines the Proximity Vector. The magnitude of each vector is inversely proportional to the distance. In other words, closer Walkers have greater influence than distant ones.

Angular Restrictions
Constraining the decision of the agents through angular restrictions ensures the functionality of the system (Figure 6). While the "arcAngleWlk" and "devAngleWlk" parameters control the agent Walker, "arcAngleFrk", "devAngleFrk" and "tolAngleFrk" the agent Fork. The "arcAngle" controls the extension of the arc. In other words, it determines the maximum angle that an agent can move away from the Steer Vector. On the other hand, the "devAngle" parameter controls the maximum angle of rotation and limits the positioning from the previous direction or from the origin. In the case of the Fork, the variable "tolAngleFrk" controls the minimum angle between Walk-

ers to avoid overlapping of the route. The calibration of these variables allows effective results and drives their performance.

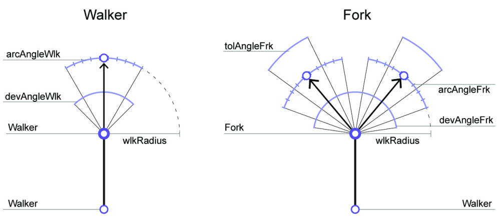


Figure 6
Angular restrictions in Walker agent (left) and Fork agent (right)

VALIDATION

We validate four aspects of ABS: effectiveness, differentiation, performance and control. Effectiveness evaluates that the circulations connect the access points with the objective points. Differentiation identifies the qualities that emerge from the results. Performance compares the values of the criteria and their average. While control verifies the coherence of the variation of the inputs with the response of the system. The results of sample populations of alternatives for the two scenarios allow to statistically evaluate the above aspects. The population is the universe of combinations that the system can generate within the thresholds of the inputs. For each nine inputs of the system, a minimum, an intermediate and a maximum value determine the scope of the design space. From this potential space, we evaluate a sample of design options that are significantly different to represent the diversity of the population. The same input ranges are implemented in both scenarios to obtain comparable results, with the exception of the “frkRadius” input due to the differences in dimensions between the lands. While for PB the range is 150 to 300m. for LV is 100 to 200m.

Effectiveness and Differentiation

The percentage of valid results of a population measures the effectiveness. The result is valid when the access are connected to the target points. The parameters associated with the failures are those that control the angular field of positioning of the agents: “arcAngleWlk”, “devAngleWlk”, “arcAngleFrk”, “devAngleFrk”. This is due to abrupt changes of direction resulting from the proximity criteria, which exceed the angular restriction threshold of these parameters. To induce the population towards valid results, the domain of these parameters must be restricted by increasing or reducing the limits of each parameter. Greater angular values imply a greater freedom of positioning in each iteration, resulting in a greater differentiation of results.

Four populations of 32 results in each scenario facilitates the assessment of the efficiency and differentiation. Each population has a range of Angular Restriction (Table 1), based on a progressive reduction of the angular domain. The percentage of effectiveness for each rank shows the difference (Table 2). PB reaches 100% in the range of greater angular restriction. However, LV does not exceed 75% due to the concavities that represent an extra difficulty to reach the target points (Figure 10A).

Table 1
Ranges of Angular restrictions

Range N°	min	middle	max
Range 1	30	105	180
Range 2	60	120	180
Range 3	30	75	120
Range 4	60	90	120

Table 2
Percentages of Effectiveness

Scenario	Range 1	Range 2	Range 3	Range 4
PB	65,60%	96,80%	84,30%	100%
LV	28,10%	75%	59,30%	75%

Regarding the differentiation, four results represent the populations by each range (Figures 7 to 14). The results show variations of the density of the circulation networks. In the case of PB, the first two ranges (Figure 7 and 8) reach high levels of the same density variation. In their most extreme cases they produce parallel paths that tend towards the pathological threshold. In contrast, ranges 3 and 4 have routes that tend to be more straightforward. For the LV scenario, high density results are recurrent in all ranges due to the narrow territory and the direction of the slope.

The interaction with the topography is the most

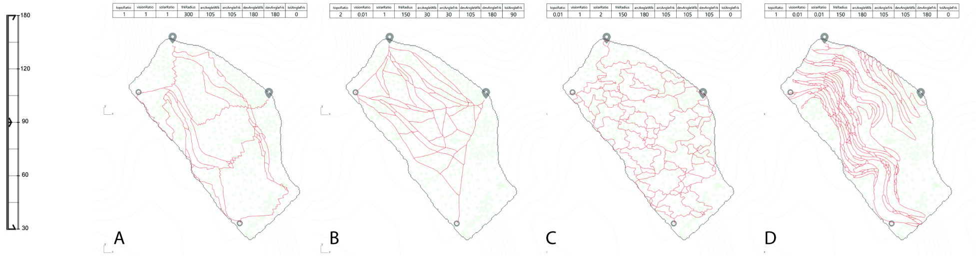


Figure 7
Range 1 PB

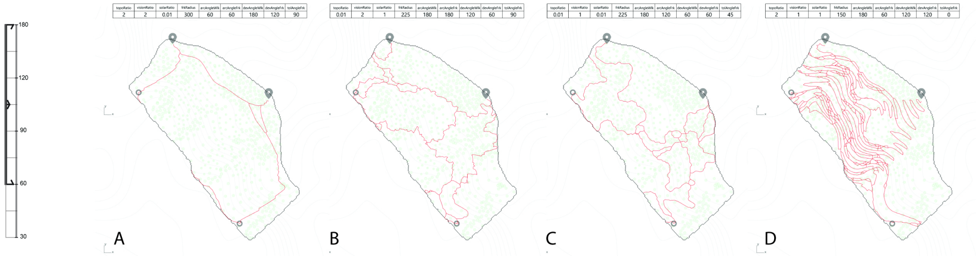


Figure 8
Range 2 PB

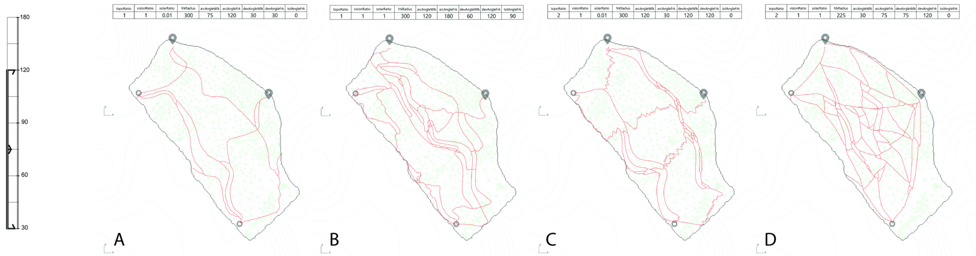


Figure 9
Range 3 PB

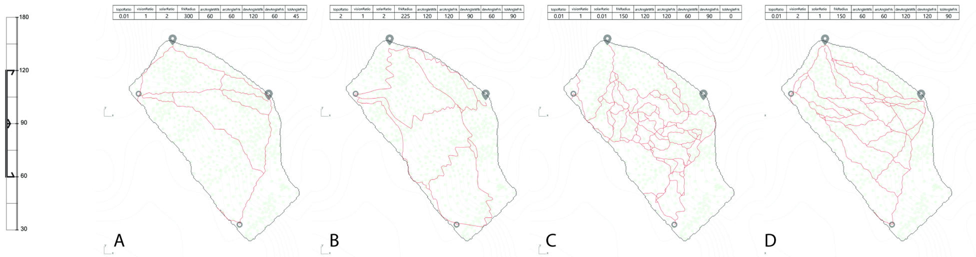


Figure 10
Range 4 PB

Figure 11
Range 1 LV

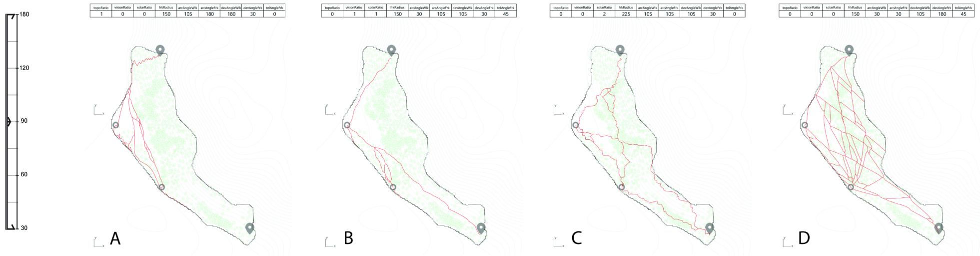


Figure 12
Range 2 LV

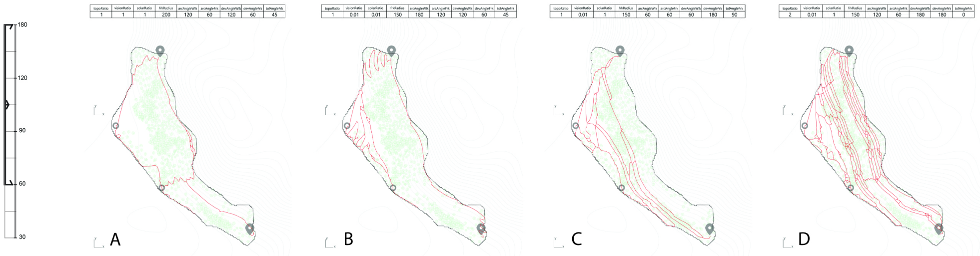


Figure 13
Range 3 LV

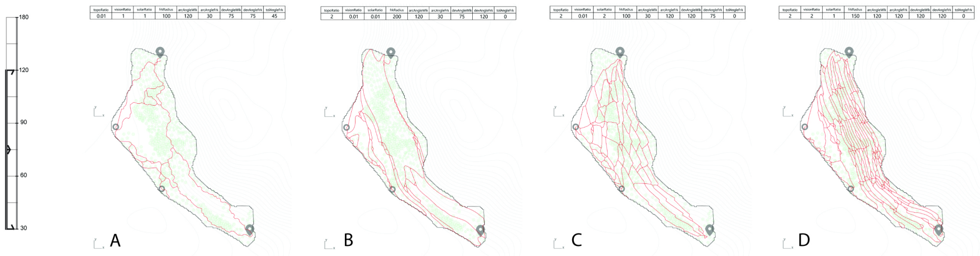
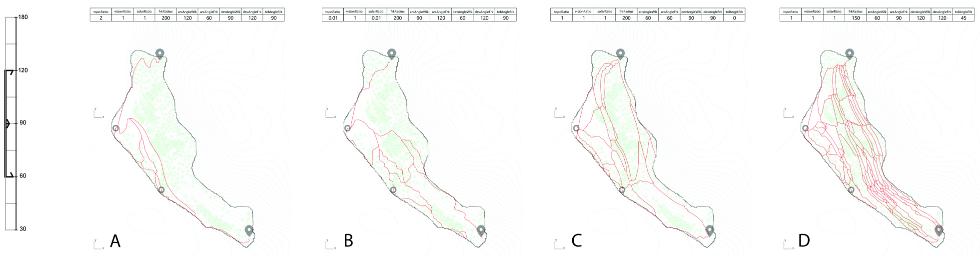


Figure 14
Range 4 LV



radical result. The routes follow the slope generating sinusoids at different degrees of intensity. From extensive frameworks along the horizontal areas (Figure 7D and 13D), to paths with undulations (Figure 9B and 11B). An erratic sinuosity persists throughout all populations (Figures 7C, 8B, 10C, 11C and 13A). This can be explained by the wide angular range and a low value of "topoRatio" that induces the continuity of the routes due to the homogeneous distribution of the topographic values.

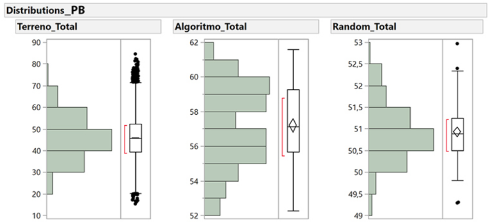


Figure 15
Distributions of average performance values in PB scenario

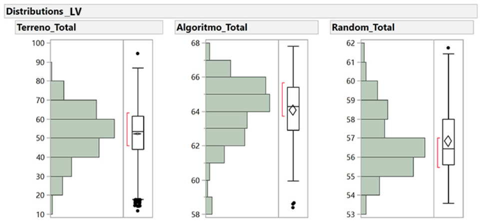


Figure 16
Distributions of average performance values in LV scenario

Topo_PB	Terreno	Algoritmo	Random
maximum	100	95,9	75,1
quartile	73,9	88,8	71,5
median	57,9	83,8	70,2
quartile	34,6	78,7	69,1
minimum	0	65,1	66,4
Mean	53,7	82,8	70,3
N	19478	128	128

Topo_LV	Terreno	Algoritmo	Random
maximum	100	96,1	83,1
quartile	77,4	90,3	75,1
median	61,7	88,1	70,3
quartile	35,9	84,4	68,6
minimum	0	72,4	60,5
Mean	56,2	87,1	71,5
N	9405	128	128

Vision_PB	Terreno	Algoritmo	Random
maximum	100	61,8	46,9
quartile	62,1	40,5	37,8
median	34,8	37	36,3
quartile	16,1	32,9	34,8
minimum	0	24,9	31,8
Mean	39,6	37,7	36,8
N	19478	128	128

Vision_LV	Terreno	Algoritmo	Random
maximum	100	79,9	57,4
quartile	84,3	62,1	49
median	53,2	53,6	45,9
quartile	6,1	46,2	42,9
minimum	0	33,8	34,9
Mean	48,6	54,2	46,1
N	9405	128	128

Solar_PB	Terreno	Algoritmo	Random
maximum	100	65,1	48,6
quartile	58,6	54,7	46,9
median	41,3	50,8	45,8
quartile	24,1	46,9	44,4
minimum	0	34,3	37,8
Mean	44,4	50,9	45,5
N	19478	128	128

Solar_LV	Terreno	Algoritmo	Random
maximum	100	69	59,9
quartile	79,3	58,9	55,3
median	41,3	50,3	52,7
quartile	25,5	43,9	50,4
minimum	0	30,8	44,8
Mean	51,7	50,8	52,7
N	9405	128	128

Table 3
Distribution values for topography, vision and solar criteria in PB scenario (Left) and LV scenario (right).

Performance and Control

The performance and control are evaluated through a population of 128 results for each scenario. The resolution of the inputs "topoRatio", "visionRatio" and "solarRatio" varies from three (0, 1, 2) to five states (0, 0.5, 1, 1.5, 2). To evaluate the performance, we compare the distribution of the results of the population with the terrain and a pseudo random population based on the values of the criteria and the total average (Figure 15 and 16). The values of the complete terrain consists of all the points of the mesh. The proposed ABS surpasses them with a difference of 11.3 units in PB and 11.9 in LV. The pseudo random population maintains the proximity criteria, but the positioning of the agent is random. The ABS exceeds this case with an improvement of 6.3 and 7.3 units in the total average in each scenario. However, regarding the vision criteria, better results are not always achieved (Table 3 and 4) because the topography values can be high if the agent is aligned with the slope, which makes it prevail over the other criteria.

The evaluation of the control verifies the coherence between the intentions of the user and the values of the performance. We compare the variation of the inputs and the response of the outputs through an Effect Tests (Table 4) and a Sensitivity Analysis (Figure 17 and 18). The Effect Tests quantifies the influence of the inputs on each criterion to be optimized through the value of "Sum of Squares". The parameters "topoRatio", "visionRatio" and "solarRatio" have a high influence in both scenarios. In addition, the parameter "arcAngleWlk" is the one that has a greater influence on performance since increasing the potential positioning range increases the possibility of finding an optimal sector. The "topoRatio" parameter follows.

The Sensitivity Analysis graphs the curve representing the variation of each criterion according to the variation of each input. In other words, it shows the effect of an input over a criterion. When the parameters "topoRatio", "visionRatio" and "solarRatio" increase, their respective criteria also do so. On the other hand, there is evidence of conflicting behaviour with the criteria of sight and sun exposure since they show a descending opposite curve. This is because the zones with greater amplitude of vision are the most exposed to sunlight, since vegetation is the only obstruction.

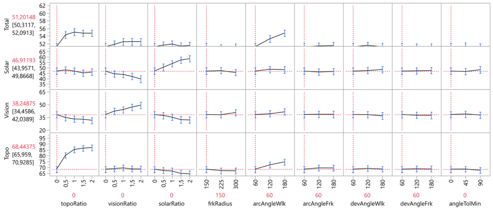


Figure 17
Sensitivity Analysis for PB scenario

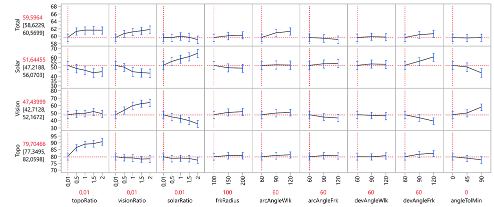


Figure 18
Sensitivity Analysis for LV scenario

DISCUSSION

Although the results in terms of performance are not as prominent yet, they are understood as a preliminary development. The algorithm shows coherence among the input parameters that control design intent, the intensity of the criteria, and the response of the configuration. The proposed ABS approach is suitable to generate catalogs of circulation networks in open spaces informed by the context for early design stages.

The generations with greater influence of the topography lead to better results. When the agents follow the slope in some intensity, the network of circulation turns out to be more coherent with the environment. One possible explanation is that the topography criterion has a continuous distribution of its values, unlike sight and sun. The reading of the environment should not be only a process of reference to isolated values, it should be post processed for the coherence of the result. In other words, the quantification of the environment can be an autonomous process in the development of systems of continuous generation. This can be through a post-reading method calculated during the operation of the system, or through a pre-process of distribution of the values to read. Future developments of the algorithm include exploring the variation of proximity criteria, improving the effectiveness of the model and increasing the potential for differentiation to assist creative design tasks.

Table 4
Effect Tests per criteria in PB (Left) and LV (right)

Source Vision	Sum of Squares
topoRatio	705,0
visionRatio	1850,8
solarRatio	836,1
frkRadius	177,1
arcAngleWlk	225,8
arcAngleFrk	2,7
devAngleWlk	63,5
devAngleFrk	20,7
tolAngleFrk	30,6
Source Solar	**Sum of Squares**
topoRatio	106,7
visionRatio	729,9
solarRatio	2238,4
frkRadius	67,0
arcAngleWlk	67,2
arcAngleFrk	14,6
devAngleWlk	54,0
devAngleFrk	5,1
tolAngleFrk	61,9
Source Topography	**Sum of Squares**
topoRatio	6034,9
visionRatio	20,6
solarRatio	288,2
frkRadius	49,4
arcAngleWlk	817,0
arcAngleFrk	32,0
devAngleWlk	11,3
devAngleFrk	2,0
tolAngleFrk	25,4
Source Total	**Sum of Squares**
topoRatio	258,9
visionRatio	36,1
solarRatio	7,22
frkRadius	2,6
arcAngleWlk	269,4
arcAngleFrk	2,1
devAngleWlk	3,3
devAngleFrk	0,2
tolAngleFrk	0,7

Source Vision	Sum of Squares
topoRatio	238,6
visionRatio	4693,7
solarRatio	2172,8
frkRadius	376,2
arcAngleWlk	218,3
arcAngleFrk	437,6
devAngleWlk	48,0
devAngleFrk	1499,6
tolAngleFrk	2379
Source Solar	**Sum of Squares**
topoRatio	990,3
visionRatio	1427,1
solarRatio	2457,7
frkRadius	216,7
arcAngleWlk	7,8
arcAngleFrk	109,4
devAngleWlk	55,6
devAngleFrk	1703,8
tolAngleFrk	1443,9
Source Topography	**Sum of Squares**
topoRatio	1962,6
visionRatio	47,6
solarRatio	81,2
frkRadius	18,3
arcAngleWlk	43,5
arcAngleFrk	16,0
devAngleWlk	16,5
devAngleFrk	141,4
tolAngleFrk	107,8
Source Total	**Sum of Squares**
topoRatio	74,7
visionRatio	70,1
solarRatio	10,5
frkRadius	8,8
arcAngleWlk	61,9
arcAngleFrk	6,0
devAngleWlk	1,0
devAngleFrk	23,6
tolAngleFrk	0,5

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