

Creativity With the Help of Evolutionary Design Tool

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Abstract. *The general thematic of our work tackles the question of the generative design tool efficiency to stimulate a creative architectural conception in the context of sustainable development. We focus our point of view on the conceptual research phases. We would like to characterise the human creative mechanisms in a situation of generative assistance where digital tool reveals some degree of autonomy and incorporates environmental constraints. Thus, we implement an evolutionary design tool in which energetic performances of the analogon are used in order to orient the evolution. Our tool is based on an interactive genetic algorithm that ensures both a broad exploration of the solutions space and the subjective user preferences accounting. Users groups were confronted to the tool in a conception situation and creativity was evaluated and characterized.*

Keywords. *Interactive genetic algorithm; evolutionary design; creativity; environmental parameters.*

INTRODUCTION

The general thematic of our work tackles the question of the generative design tool efficiency to stimulate a creative architectural conception in the context of sustainable development. We focus our point of view on the conceptual research phases. These moments of conception reveal an important creative dimension and their digital instrumentations have been reviewed since a few years. We would like to characterise the human creative mechanisms in a situation of generative assistance where digital tool reveals some degree of autonomy and incorporates environmental constraints. Thus, we implement an evolutionary design tool in which energetic performances of the analogon are used in order to orient the evolution. We mark the emergent situation in which the designer is becoming a meta-designer, describing the conditions of behaviour more than the final shape. Moreover, chance plays an active role during the generative and evolutionary pro-

cesses, and we speak about a generative algorithmic hazard in order to characterise this phenomenon that must stimulate an inventor's interpretation. This paper will first present the interactive genetic algorithm that we have implemented and particularly the human-machine interface functionalities, and second, the results of our experiments regarding creativity mechanisms at work.

EVOLUTIONARY DESIGN TOOLS

Evolutionary algorithms are various; there are generally genetic algorithms, evolution strategies, evolutionary programming and genetic programming. The genetic algorithm is probably the best known of all evolutionary search algorithms. These algorithms are part of the computing intelligence family and they are traditionally used to solve optimisation problems. They offer two advantages: on the one hand, their application flexibility and on the other

hand their robustness to address difficult problem with local optimums.

Starting from J. Holland in 1975, in order to explain the adaptive processes of natural systems and to design artificial systems based upon these natural systems, there are several examples of the use of genetic algorithms in the field of architecture. The works of John Frazer, Peter Bentley (Bentley 1999), and Paul Coates represent the first experiments in the area. During these last years we note a continual interest for the use of these algorithms and today we can expect a maturation of the technology. For example, Hemberg (Hemberg et al. 2007) searches to stimulate the creativity with a surface generator; Caldas (Caldas 2005) optimizes housing composition; Besserud (Besserud and Cotten 2008) distorts building envelope; Dillenburger (Dillenburger and al. 2009) synthesizes building and Turrin (Turrin et al. 2010) optimizes a solar roof.

Evolutionary algorithms have been traditionally used to solve optimisation problems. In addition, they can be used as a design aid. The evolutionary approach is a generate and test approach which fits the procedures for design synthesis and evaluation in the design process. The characteristics of the approach are:

- A pool or a population of design solutions is used rather than a single solution.
- Individuals are selected according to their adjustment to the fitness functions.
- New solutions are generated through mutation and crossover of previous elite.
- In addition, these design evolutions can be used as an aid in stimulating the designer's creativity.

INTERACTIVE GENETIC ALGORITHM

In case we cannot define precisely what we want to optimise, it is necessary to develop specific strategies. In the situation in which the evaluation is not measurable with the help of a mathematical function, for example the notion of satisfaction or aesthetic qualities, it's possible to convoke the human interaction in the evolutionary loop. This result is the

implementation of an interactive evolutionary algorithm. If the first experiments were concerned by artistic or music creations, many studies nowadays evolve subjective judgments in various domains of application (Bentley and Corne 2001).

That does not prevent us from difficulties and limits. Considerations on the user's fatigability, a too wide number of repetitive interactions, an impossibility for a human to consider an important population or the user's boring are all contributing to invent intelligent modalities of interaction and ergonomic interface. The usual techniques aim to decrease the population size, as well as the number of generations; they intend to automatically select the solutions in function of previous user's choices, to decrease the complexity of the genotype in order to preserve live interaction. Moreover, in the case of a multi-objective approach, it is difficult to introduce a human interaction. It is often difficult to identify the criteria to which the user wants to give a priority. However, in a situation of conception, the designer must be able to evaluate the consequences of his choices and selections. Two algorithmic modalities are usually proposed here: the first is the possibility to control the mutation rate and the second is an approach by a "cumulative selection" which is a genes prioritisation (Romero and Machado 2007). In addition, a special attention is given to the interface ergonomic principles.

THE NOTION OF CREATIVITY

The creativity is the capacity to produce, simultaneously, something new and suited to the context. The production is called new depending on its originality and its unexpected characteristics, but it must be also adapted to the situation and it must satisfy several contextual constraints. The notion of novelty is relative. Boden (Boden 2003) proposed to separate the "psychological creativity" (personal creativity) from the "historical creativity" (function of the production already done). The intuition, the cultural and the educational background play an important role in the creative process and the mental activities at work represent a combination of rationality, intui-

tion and creativity (Candy and Edmonds 1999). Exploration, generation and evaluation compose three main activities of the creative process. The creative solution emerges from analogy, metaphor, selective comparison, selective combination or multiple generations of possibilities (Bonnardel 2009). The conative factors (style, personality, motivation) and the emotional factors can complete the model (Lubart and al. 2003). The designer's sagacity and his interpretative glance participate in the perception of anticipated qualities of the solutions.

CASE STUDY: EC-CO-GEN-L TOOL DESCRIPTION

Our case study is based on the implementation of an interactive genetic algorithm. We have seen that the general theme of our work focuses on the generative capacity of digital devices to stimulate a creative architectural design in the context of sustainable development. The tool will assist the architect in his design process, and will allow the identification of eco-efficient solutions in a specified context, in terms of climate, urban integration and programmatic needs, without stifling creativity and allowing the emergence of creative and unexpected solutions. Thus the tool must facilitate access to a rational understanding, knowledge objectified in terms of performance evaluation, while allowing for subjective interpretation and individual choices based on the tacit knowledge of each architect.

We use environmental constraints to orient the evolution, our own energetic simulation engine makes the individual evaluation; a morphogenetic engine is defined and based on the coagulation of individual entities called voxels; a machine-human interface allows an interaction between the systems and the architect. The designer has the ability to orient the evolution in function of subjective or aesthetic interpretations; he can make choices while acknowledging the performance behaviour of the solution.

Morphogenetic engine

In the latter case, the parametric model of the gen-

erated analogon is determined. The designer focuses his activity on his interaction with the evolutionary loop. The specificity of this solution relies on the integration of an interactive genetic algorithm.

The morphological model used is based on an agglomeration of elementary units, called "voxel" (volumetric pixels), whose geometry is currently reduced to a parallelepiped of fixed size. These "voxels" take place in a three-dimensional matrix space and represent spatial units. The matrix limits are defined by the initial plot shape and constraints by legal urban regulation, both in the plan definition, in the maximum height and in its urban alignment. The faces of the voxel have a material specification, in terms of insulation and opacity. They receive solar energy and contribute to heat exchange. Each "voxel" is also associated with programmatic functions. The generative stochastic process fills the matrix space with either an active "voxel" or a void cell.

The input data consist of the geometric description of the plot, the urban environment and their geolocation. An objective of constructed area is also defined for each programmatic function.

Evaluation engine

The evaluation engine combines three fitness functions: the compactness of the building, the shadows evaluation on the urban environment and the thermal performance evaluation (figure 1). The shadows evaluation on the built environment is calculated by ray tracing on a matrix of dots arranged on the urban context façades. Six solar positions are selected, and the average shade during the period is determined. The shading must be minimized. The calculation of heat balance is based on the simplified model of Unified Day Degree method. This allows an approximation of the heat balance of the building envelope, specifically for winter comfort. It takes into account the glass surfaces and free solar heat contribution, function of the project localisation, and losses in transmission, function of the envelope thermal resistance, for which the coefficient is fixed. The gap of living space available, from the surface target, specified in the initialization process, should be minimized.

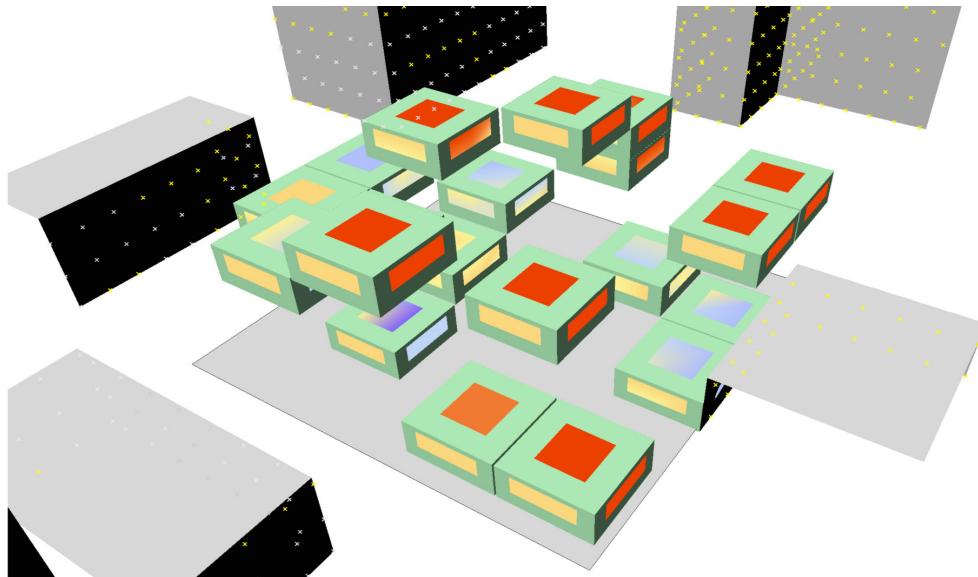


Figure 1
Phenotype representation
used for the performance
evaluations.

Interactive genetic algorithm

One of the project specificity is based on the integration of an interactive genetic algorithm (IGA). This allows the designer to interact with the evolutionary loop. He can drive and orient the evolution according to its own subjective interpretation of the aesthetic qualities of the analogon. The integration of a human interaction in the loop evaluation can introduce a tacit knowledge in the selection constraints. However, this interaction encounters a number of limitations: slow process associated with the time of awareness, population size limitation, simplified evaluation required in order to maintain a real-time interaction, weary of the designer in front of a wide number of generations. Our proposal incorporates a dual mode of genetic evolution: the automatic generation selection process that can remain independent or be interrupted by a human interaction. Then the designer has the possibility of privileging individuals and orienting the evolution trajectory in a chosen direction.

A “gene class” represents the genome description; it is composed of the voxel status and its cor-

responding index inside the matrix space. The status could be active, associated to a programmatic urban regulations. A “chromosome class” describes an individual; it is composed of the “gene class” and the fitness table associated. Starting from the “gene class”, the “evaluation engine” builds the corresponding 3D model and makes evaluation based on this phenotype representation (Figure 1). Three different populations are preserved during the whole process: the current population, the total population from the first generation and the Pareto population. The Pareto front is evaluated by a single fitness function merging randomly the three independent objectives (Jaszkiewicz 2002). In order to simultaneously promote diversity and fitness within the population, we use the ACROMUSE method (Mc Ginley and al. 2011). It allows adapting crossover, mutation and selection rates in function of two population diversity measures. A Standard Population Diversity (SPD) is calculated, this index is variable and drives the crossover and mutation rates. Meanwhile the Health

Figure 2
Machine-Human Interface.



Population Diversity (HPD) combines fitness and genomic diversity in order to modify the selection pressure, this ensures both the population diversity and the high performance solutions. A pheromone is used as a mark and associated to the pool of individuals selected; this pheromone could evaporate in order to reflect the recent user choices or could be fixed for a specified number of generations.

Machine-Human Interface

The Machine-Human Interface is organised by two screens. The main one allows the elite population visualisation, the second one zooms in the phenotype representation. The first screen is divided in three main parts (Figure 2): the current elites population, the selected individuals collection and the algorithm preferences composed by the evaluation parameters and the constraints values. The zoom window presents the phenotype representation integrated inside the urban context; it is possible to manipulate the 3D model in rotation and to display the performance outline (Figure 3). These two kinds of information allow both a subjective interpretation

and an access to an objective knowledge, the relative and the absolute performance of the analogon.

The architect has the possibility to select one or more individuals and to keep them available for subsequent manipulations. These selected individuals constitute a collection. At any time during the process, the architect can export them or inject them inside the evolutionary loop in order to redirect the optimization, to rebalance the Pareto front by favouring these new entering.

Originality of the solution

This tool reveals a double originality. On the one hand, at the Human-Machine Interface level, it offers the display of a population of privileged elites, but a gene pool is kept and stored in a larger population of individuals. A multi-generational process between each iteration and human interaction is integrated; it speeds up the convergence process and reduces user's weary. On the other hand, at the genetic algorithm level, a mechanism for persistence of user choice is integrated and can take into account both subjective and objective evaluations.

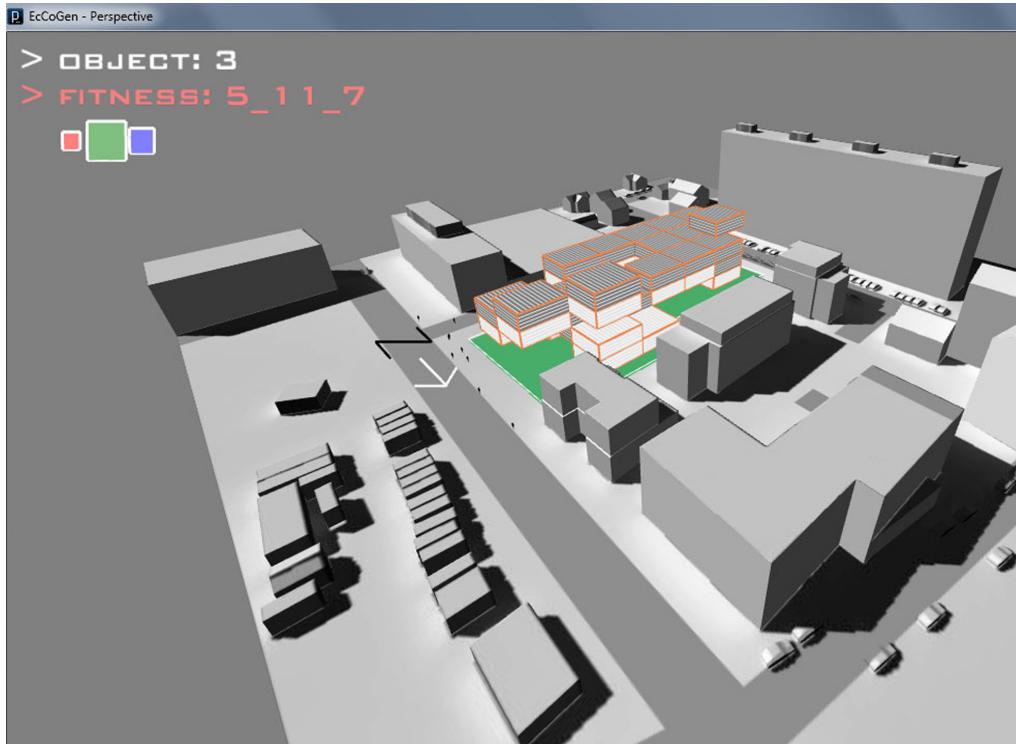


Figure 3
Zoom window.

Both the Jaskiewicz's MOGLS adaptation and some gene pheromones are used to bias the fitness relative proportions and the crossover process in order to reflect the user's preferences during the run of the algorithm. Moreover, adjusting the algorithm to provide diversified solutions while taking into account the choices and selections of designer is solved by the use of an adaptive crossover and mutation rate, based on the ACROMUSE method.

CREATIVITY EVALUATION

Experimental protocol description

In our experiment we mobilized two groups of two students, who realized two sketches of an architectural project. The program, the site and the performance objectives were given and the students had

three hours of working time in order to produce characteristic draws, façades and perspective views of their project. They were not limited in their tools and supports and they could use any software starting from Ec-Co-Gen tool.

Three cameras captured students' activities and all drafts, diagrams and schemas produced were collected at the end of the session: they constitute the marks of the design activity and represent a series of intermediate objects of mediation. A questionnaire was proposed at the end of the exercise and a post session interview was organized in order to revert to the feeling of the students, to collect propositions and to identify limits and constraints. The objective is to observe in which proportions the tool supports the creative activity and how it becomes resources for decisions.

Creativity characterization

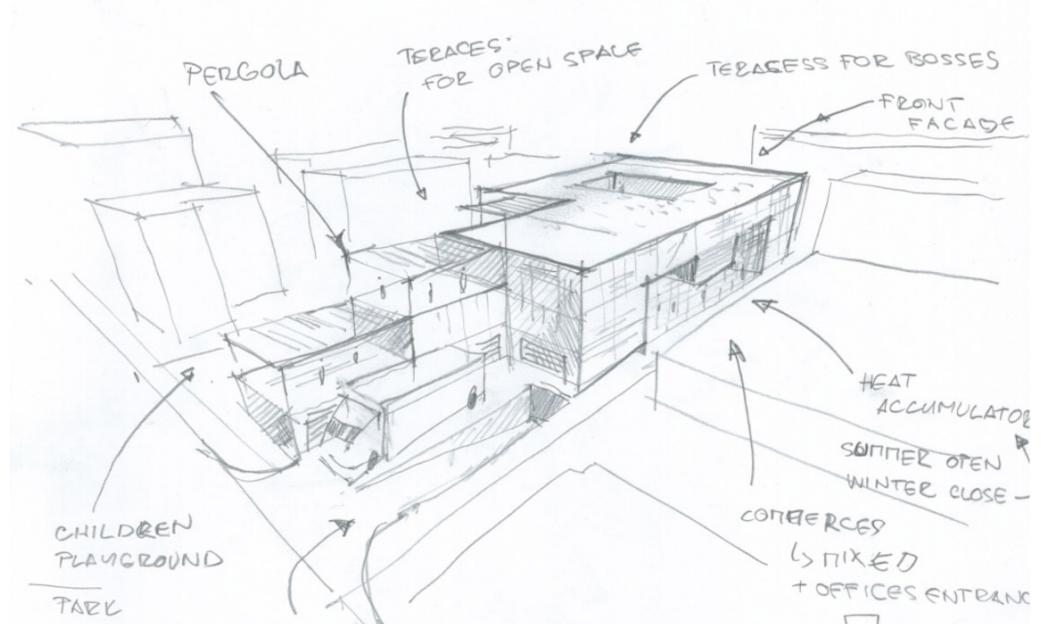
Starting from the data collected, we aim to characterise the creativity mechanisms involved during this generative design process. Four dimensions structure our analysis. First, the originality degree of the solution proposed. It is based on the analysis of the difference between the distinctive features of a reference solution and those of the solution proposed. A qualitative critic conducted by the experts could complete it. Second, the creativity mobilised during the design process is measured with the help of fluidity and flexibility concepts coming from the divergent thinking method. The fluidity represents the number of ideas generated; the flexibility represents the number of ideas categories. Third, the creative cognitive activity is identified with the help of all kinds of marks we have collected: the draws, the gestures and the dialogues between the designers are taken into account. Fourth, the way of appropriation, the use of the tool and the designers' recommendations mark the tool potentialities and improvement.

First results and comments

The data reduction is still under process but first results and comments could be proposed. Concerning the degree of originality, it seems that the students take into account the environmental factors, they are parameters of the generative engine. They clearly become explicit constraints and mediation support. The suggested solutions respect the initial constraints of the brief and present an important degree of definition in relation with the duration of the exercise. The sketches offer many opportunities and combine architectural principles in an integrative proposition, the projects can be considered as original. The figure 4 shows an example of students' sketch, starting from the digital model exported from Ec-Co-Gen-L, the students decided to draw by hand an annotated view.

Concerning the divergent thinking measure, it's difficult to evaluate the activity flexibility but it is easier to quantify the fluidity. During two-thirds of the time, the students explore the solution space by

Figure 4
Example of students' sketch.



generating solutions. The two groups of designers made fifty and sixty-five generations and respectively six and four preferential solutions were kept.

If we crosscheck these elements with the verbs, gestures and diagrams produced, it clearly appears that the tool is used as a support of the exploration activity. It allows the understanding of the interactions; the students try to understand the global performance in regard with the site conditions. Moreover, the tool is used as a generator of ideas that allows selective combination, selective comparison, analogy and multiple generations. The solutions generated become the support of the collaboration between the two designers and they stimulate the ideas exchanges and convergence.

The tool is relatively simple to use and one group has hijacked the software by combining two generated solutions in a final project. Numerous remarks were made concerning ergonomic features and new functionalities needs.

The main limits concern the global understanding of, on the one hand, the link between performance and form, and on the other hand, the position of the solution inside the solution space, that is to say the representation of the solutions populations global behaviour. Our initial intention was to propose a phylogenetic visualization of the generated solutions, but we failed in this direction. Another hypothesis could be to visualise the epigenetic landscape. Its behaviour during generations and the position of the elites population could give a global view of the state space allowing the designer to appreciate this multiplicity.

CONCLUSION

In this article we have presented the Ec-Co-Gen-L tool, its components and functionalities. We have marked the double originality of this interactive genetic algorithm, the one based on the limited number of elites displayed while a broader number is kept in order to ensure diversity, the second that allows the persistence of user's choices during the generations and the selection operations.

We have described the experimental protocol we used in order to evaluate the quality of our tool to stimulate and support creativity. We have characterised the creativity mechanisms operating during a generative instrumented design and we have particularly identified the necessity of building the epigenetic landscape visualization.

Finally, we mark the fact that the quality of the solutions generated are associated with the critical distance taken by the designer during his conception activity. Thus, if the tool facilitates the ideas convergence and helps reasoned decision-making, it must participate in the construction of dissensions that must stimulate and allow combinations, comparisons and confrontations.

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