Integral evolutionary design, integrated to early stage of architectural design process

Generative exploration of architectural envelope responding to solar passive qualities

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Abstract: This paper tackles the exploration of generative digital tools in the field of architectural design. Evolutionary mechanisms are expected to help the designer and to support his creativity. Our purpose is to implement a digital tool based on a genetic algorithm, which uses environmental parameters and human interplay to evolve an architectural form. The analysis of design processes and CAD use lead us to mark a transformation of design process at a cognitive level.

1.   INTRODUCTION

Natural mechanisms provide some guides to develop some digital tools, which can help designers to drive their exploration in a creative way. This research explores the way the designer could use computer and scripting in order to explore a space of possible solution. The use of generative process rather than simulation is thus proposed as a way to integrate the computer media in the design process.

We firstly characterise the architectural design process and we focus our point of view on the inadequacy of the common use of CAD software. We try to show what generative processes suit a creative design, and we note a shift from an implicit to an explicit thinking.

The last part presents our experiment. We focus our work on the early stage of design process and we implement a genetic algorithm to evolve an architectural form evaluated by its solar passive qualities and by the designer's interplay.

2.   RELATED WORKS

2.1   Integral evolutionary design

Evolutionary algorithms are various; there are generally genetic algorithms, proposed by J. H. Holland in 1975, evolution strategies proposed by P. Bienert, I. Rechenberg and H. P. Schwefel in 1960, evolutionary programming proposed by L. F. Fogel in 1966, and genetic programming developed by J. Koza in 1992.

Genetic algorithm is probably the most well known of all evolutionary search algorithms. 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. Caldas (Caldas and Norford, 2003) drive optimisation of building envelops through a genetic algorithm to minimise HVAC, lighting energy and construction costs. Malkawi (Malkawi 2003) offers a java environment using a genetic algorithm as an evolution algorithm and CFD performance as an evaluation mechanism. Nishino (Nishino and Takagi, et al, 2001] provides an example of an interactive evolutionary computation applicative to a creative design process. Other examples include parametric design generation in order to define initial generic geometry. Genetic generation is then used to drive the design (Krishnapillai 2004)

In general, evolutionary design could be divided into four main categories: evolutionary design optimization, creative evolutionary design, evolutionary art and evolutionary artificial life (Bentley 1999). We are more interested here by the notions of creative evolutionary design and evolutionary design optimization. Their overlapping is usually called integral evolutionary design.

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 population of design solutions is used rather than a single solution.
   - Individuals are selected according to their adjustment to the fitness function.
   - New solutions are generated through mutation and crossover of previous elite.

With the advent of the new technologies in the field of design evolution, the designer's role shifts from that of a creator of individual instances of a style to that of a meta-designer or creator of an entire style of family (Soddu 2004). Design-as-Product or Ideas-as-Product as defined by Soddu, is focused on the act of designing the species representation or "DNA" of a designed object.

In addition, these design evolutions can be used as an aid in stimulating the designer creativity (Todd and Latham, 1992). The advantage of such an evolutionary approach is the creation of diverse sections of the state space that increases the possibility of discovering a variety of potential solutions (Rosenman, 1997).

2.2   Architectural design

Most definitions of design describe it as a goal-oriented process, where the goal is a solution to a problem, the improvement of a situation or the creation of something new and useful.

The design process system needs to formally represent the field of interest and then to find some method of sequentially searching in that field. This means that all the possible representational states must be defined

before any problem solving can begin. The design system cannot contribute in a direction that is not specified in the initial design space.

This acceptation focuses on how to search efficiently and effectively the design space; some example could be found in expert systems and constrained-based systems. Broadly, the computational interpretation of this consideration sums up to research optimisation algorithms. The extension of numeric-dimension domain of search to a symbolic domain introduced the notions of configuration and combinations and thus allowed shapes grammar engines.

Other acceptations of designing reformulate the process. Simon gave a special class to architectural design process and spoke about ill-defined problem or ill-structured problems. Gero (Gero and Maher, 1998) suggests to consider the design activity as designing. Designing involved not only a search but also a reformulation of the search space; the design space changes over time. New knowledge is learned during the design activity and contributes to reformulate the purposeful of the design process. Guibert (Guibert, 1987) gave this definition: "Design process is a formulation/resolution concomitant of implicit problem never resolved nor described definitely." The convergence of the solutions is parallel with the understanding of the problem; solutions and problems co-evolve during the whole design process: finding a solution requires in addition to find out what the real problem is. Boudon postulates that "the process of conception is a diachronically one that implies a progressive transformation of what a project is" (Boudon, 1994).

Through a computational point of view, a process of meaning communication between the design system and user emerges. Thus an interaction between the user and the digital tool is necessary. The digital tool is a support of the mental representation of the designer. The designer explores the solution space and in the same time, he reformulates the problem in function of his exploration.

Moreover we consider the architectural design process as a creative and non-routine one. Gero (Gero and Maher, 1998) defined the notion of creative, routine and non-routine process. Chupin (Chupin and Léglise, 1997) marked the importance of the analogical thinking as a mechanism able to evolve the creativity.

2.3 Digital tools

2.3.1 Simulation design process

Computer Aided Design (CAD) is typically used for visualization and analytical simulation of geometric models. Designers describe, through a Graphic User Interface, the geometric characteristics of the object under study. The software then evaluates this one. Evaluation could be linked to thermal qualities, structural properties, CFD simulation (...). Then the software suggests results to the designers. Designers can take in consideration the results, modify their proposal and re-execute the simulation process.
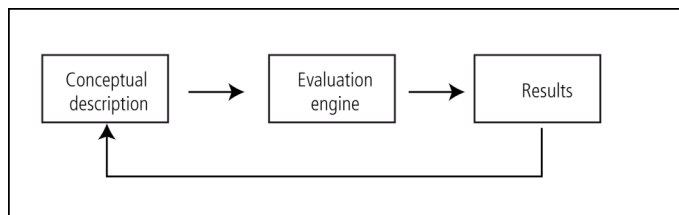
Figure 1. Simulation design process through digital tools

We are expecting that this process is not really adapted to a creative design process. Designer cannot concentrate on getting an idea from imagination. We notice two main inadequacies.

The first one is a contextual inadequacy linked with increasing interface complexity, large number of indirect manipulation, long delays to obtain results.

The second one is a cognitive inadequacy because of a gap between the design process characteristics and the digital tools necessities. Digital tools impose precision, univocal model and heavy implementation. These encodings are disturbing the creative design process. Moreover, technical simulation requires high expertise level and very sharp information, not yet established during primary phase.

2.3.2 Evolutionary design process

Evolutionary digital tools work in a different way. Generative tools assist the designer to go beyond geometric representation and post analytical simulation. Generative processes are an engine of proposals, through a kind of "digital dialogue" between the computer and the designer.
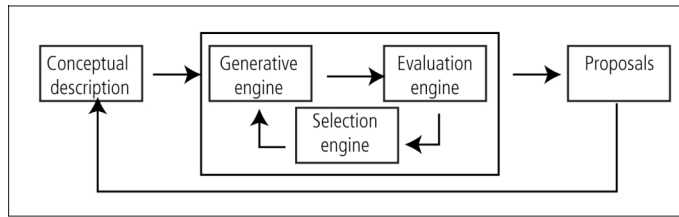
Figure 2. Evolutionary design process through digital tools

First of all, the designer has to make a conceptual description of the object under study. He sets the initial constraints. A generative engine is used to explore many solutions based on this initial pattern. Each of them are evaluated and selected or rejected. The generative process could be re-executed through crossover and mutation mechanisms. Once the number of set generations is reached, the software makes proposals to the designer. This one can stop the process or re-execute the loops.

We expect this evolutionary process to be more adapted to a creative design process. And we would like to highlight 3 main components.

First of all, an evolutionary process is based on an exploratory search of solutions space. That is a characteristic of the design process. (Boudon, 1994) Boudon postulates: "Project is informed by its figuration and doesn't constitute a prior representation".

Second, it seems very important that tools create a dialogue within the designer himself. In the same way that drawing is a support of a mental representation, targeted to the designer himself.

Third, evolutionary tools are supporting analogical thinking. They make propositions from which the designer makes choices in order to build architectural "analogons", an object to think about. The notion of architectural "analogons" is explained by Estevez (Estevez 2008) and could be extended to the analogical thinking (Chuppin and Léglise, 1997).

3.   EXPLICIT THINKING

The use of the new digital tools modifies the implicit thinking into explicit representation of the design process. The computer, by making the designer's methods necessarily structured, imposes a reflexive thinking to the designer (Loukissas and Sass, 2004). By scripting and algorithms use, the designer changes the design process in terms of cognitive level.
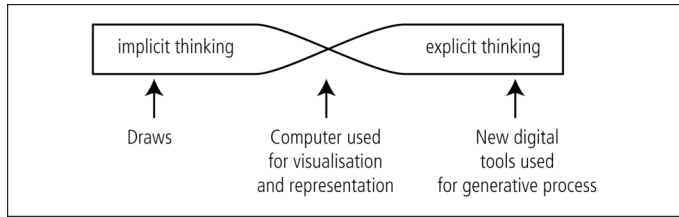
Figure 3. Shift from implicit to explicit thinking

The draws are representative of an implicit thinking, where intuitive and body movements are largely implicated. The use of computer for visualisation and representation extends the drawing methods to digital tools, but with creative limits. Generative process shifts from implicit to explicit thinking, while supporting a creative activity.

Through an evolutionary design process, the explicit description of the generative process is necessary, but this one is not about the geometric description of the object under study. That is an important difference between the current uses of digital tools and their evolutionary used. Here, the designer works on the process from which the building will be created. (Soddu, 2004) Algorithmic processes can enhance the designer's creativity not by designing objects or buildings directly, but rather by designing processes that could create buildings, or part of them.

Beyond software what is the role of programming in architectural practices? Could Architects be able to script their own processes? "Design by numbers" (Maeda, 1999) illustrates the modes of using computation as an expressive and intuitive medium for design. Algorithm is not necessarily a complex program, it could be seen as a simple encoding. A series of loops and isometric transformations can be for example very easily implemented with little or no prior experience. The computer originated as a tool for fast calculations has evolved into a medium for expression. In a certain way algorithm could be proceeded manually; the encoding step is a way to go faster. Algorithm is more a way of thinking: by the scripting and the use of algorithms, designers change the cognitive design process.

4.   EXPERIMENT

4.1   Development environment

We focus our point of view on the initial phase of the design process, where the designer is looking for ideas. In our proposition, a generative process has already been defined; an evolutionary process and a solar passive fitness compose it. It means that designer is searching an appropriate formal proposition to go further in his work in progress.

This experimentation is made through the use of 3DS Max® software, maxscript is used regarding scripting and encoding. A Genetic Algorithm had been scripted in maxscript. The final experimentation is being developed. Environmental parameters are used to drive the evolution. Solar passive evaluation is based on Unified Day Degree method, UDD, which had been embedded in maxscript. We'll come back on UDD method description below.
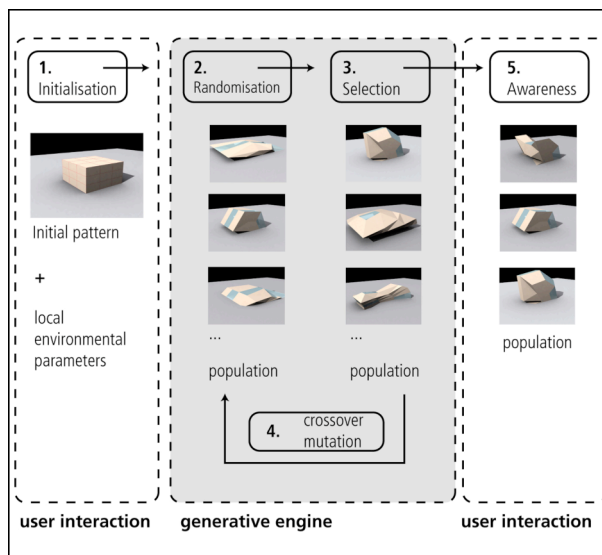

Figure 4. General representation of the process

4.2   Initial pattern

Initial pattern matches the definition of elementary genome: that is to say the first individual. The user is here initialising procedure. Initial pattern is

represented by a schematic geometric description, a sketched volume, a primary envelope containing constraints not yet explicitly described, like plot dimensions, wished surfaces, personal formal intention of the designer, mental representation of the designer…
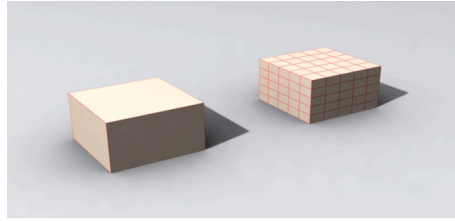
Figure 5. Initial pattern

The following three parameters will play a key role in the solution : global Dimension, global form, number of segments, vertex and faces, that is to say topological description. This one will not evolve during the evolutionary process. Considering the first two parameters, it seems obvious that they have a great influence. Regarding the last parameter, its influence is less direct, but we can imagine that more there are defined segments, more facets will be manipulated and consequently more the deformation will be continuous. In our example, our initial pattern is a simple box with three height, three length and three width segmentations.

4.3   Shape exploration

The shape exploration is based on transformations through metamorphosis. This strategy of metamorphosis refers to the work of Ching (Ching, 1979). It is based on the transformation of the object through successive geometric deformations with the preservation of the topologic properties. Operators, called inside 3D software "modifiers", make deformations. We can get the list: bending, pushing, tapering, skewing, twisting, and stretching.
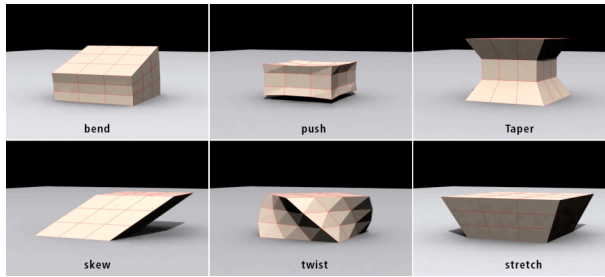
Figure 6. Modifiers

Shape explorer takes the initial model as an input to trigger the shape exploration and automatically derives various shapes by simulating natural evolution, through crossover and mutation of the genomes.
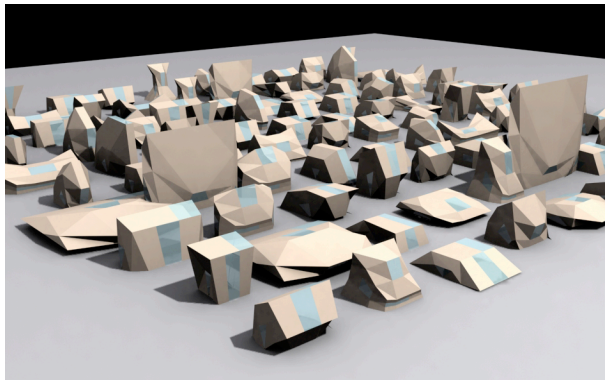

Figure 7. Possible population

4.4   Material exploration

A material explorer permits to modify each facet's properties, regarding opacity and thermal resistance coefficient. These physical qualities are stocked inside a table, and the algorithm randomly assignments an index to each facet. This index refers to physical qualities. Polygons are labelled. And the evaluation engine then uses properties.

4.5   P-type and G-type

Through genetic algorithm, each individual is represented on the one hand by his P-type, it means his phenotype, or his geometric representation, and on the other hand by his G-type, it means his genotype, or an encoded representation of P-Type. The G-type symbolises the genome of the individual.

In our experimentation the G-type is based on a derivation approach. (Rosenman, 1997) Derivation approach is based on the use of rules. Executing the G-Type's sequence derives the form. This approach means that the G-Type represents a recipe rather than a blueprint. An advantage of this solution is about the potentiality to obtain unexpected solutions. Indeed a very small change in the G-Type can lead to large and unexpected changes in the P-Type.

To go further regarding our G-Type's representation and structure, we can say that two main chromosomes compose our genome: one part is associated to physical properties of each facet, and a second part represents the description of the shape.
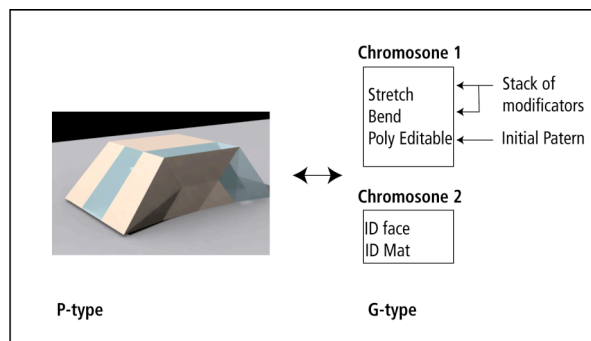
Figure 8. P-type and G-type translation

The sequence of our formal chromosome is composed by the initial pattern, described by an editable polygon, and a stacking of modifiers. The designer has the ability to edit this chromosome by simply unfolding the stack. In this way value parameters can be possibly modified.
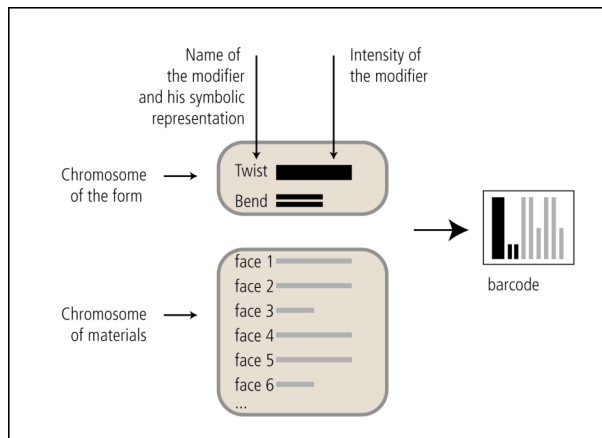
Figure 9. Graphic representation of the G-Type

4.6   Crossover and mutation

In the beginning, a random population is defined. Each individual is evaluated through the UDD engine.

Then two parents at a time are taken, and their chromosomes are cut at a random point, and reconnected together (crossover). One "modifier" of the first parent replaces a "modifier" of the second parent. Material properties of the facets are mixed in the same way. These "children" are then put into a new generation of population, and re-evaluated again, until an acceptable solution is reached, or the set limit of generations reached.
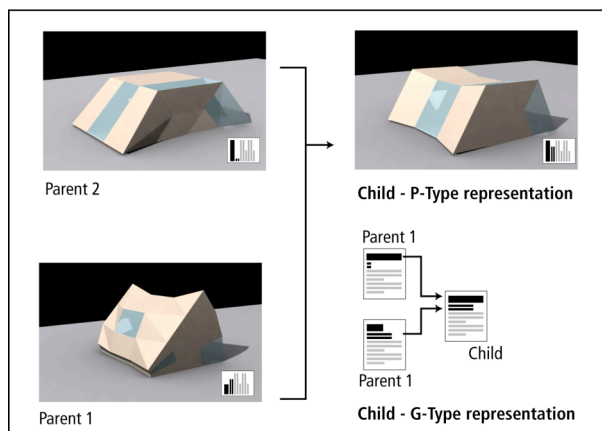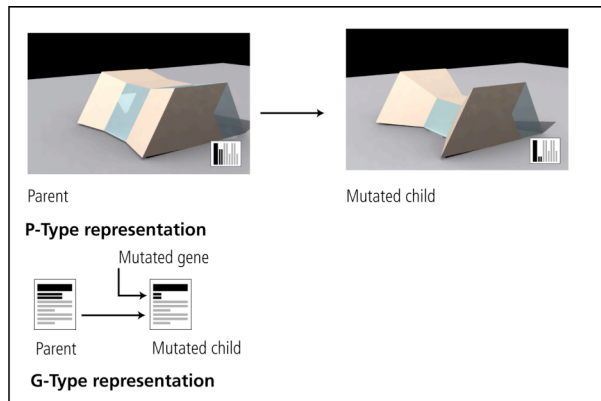

Figure 10. Crossover mechanism

Mutation mechanisms start from a selected individual and then replace randomly some parameters of each chromosome. Value of a "modifier" can

be replaced randomly, or a new "modifier" can replace a selected one. This new mutated child is then put into the new generation for evaluation and selection.

Figure 11. Mutation mechanism

4.7   Individual evaluation

The main goal of a non-routine context is to generate suitable forms that are not necessarily globally optimal, but that satisfy a range of customer, social, technical and designer requirements.

In our example, the evolutionary process is used to stimulate the creativity of the designer, and to propose a quite optimal solution regarding passive solar properties.

4.7.1   Solar passive performances

Solar passive qualities are evaluated by UDD engine. This one is based upon the Unified Day Degree method. This method is selected because of the simplification of the problem it provided. At an early stage of the design, all the parameters are not known; some approximations need to be done. We focus our evaluation on the winter comfort, and the heating needs.

Heating degree-day is a quantitative indicator designed to reflect the demand for energy needed to heat a home. This index is derived from daily temperature observations. More specifically, the number of heating degrees in a day is defined as the difference between a reference value of 18°C and the average outside temperature for that same day. The value of 18°C is taken as a reference point.

The location of the site is in the Paris area. The environmental parameters are stocked inside a table: the solar radiation on a specific tilt and orientation panel, external temperatures, internal inputs, and inertial class. Internal inputs are defined in function of the programme and of the initial brief. Intermediate values of the solar radiation between two orientations and tilts are evaluated through a linear interpolation.

The generic formula applied to calculate heat loss is :

$D = Ht.Dh(\Omega a)$ D : Heat loss of the building [kWh/year] Ht : Loss coefficient of the building [W/K] Dh(Ωa) : Value of degree hour or degree day Ωa : ambient temperature of record **$Ht = Henv + Hrev$** Henv : loss of building envelop [W/K] Hrev : loss by ventillation [W/K] **$Henv = \Sigma(A.U)$** A : Wall surface [m2] U : Loss coefficient of surface [W/m2.K] Hrev : Neglected	Heat loss (D) are offset by free inputs (AG). **$AG = AI + AS$** AG : Free inputs [W] AI : Internal input [W] AS : Solar input [W] **$AS = E.Sv.c$** E : Solar radiation function of tilt and orientation [W] Sv : Glass surface [m2] c : Transmission coefficient of the glazing **$f = AG/D$** f : Free input divided by heat loss $\mu = f(f, \text{inertia class})$ **$B = D\text{-}\mu AG$** B : heat needs [kWh] included free input.

Figure 12. UDD Method

Each individual of our population will be evaluated in function of his heat needs. The smaller the heat needs will be, the more the individual will be evaluated.

4.7.2   Aesthetic qualities:

A subjective interaction is added to the evaluation process. The engine displays the best models evolved through generations. The user can find his preferred shapes among them, getting inspirations about how to evolve the shapes to get more appealing ones, and subjectively controlling the evolution process by selecting the preferred one. Then evolutionary process could be re-executed, based on this new initial pattern. The final evaluation of satisfactory design solutions is subjective and involves aesthetic or symbolic content. The designer through human interaction makes it. This is usually called an interactive eyeball test.

5.   CONCLUSION

We pointed the fact that the design activities imply a necessary interaction between the user and the digital tool. We showed that evolutionary design process suits creative design, unlike the typical use of CAD. We suggested that the design process changes in terms of cognitive level trough the use of generative devices. We noted a shift from an implicit to an explicit thinking.

The computer through the generative process becomes a designer's partner capable of generating unexpected forms. Evolutionary algorithm could be capable to stimulate design creativity through non-deterministic exploration.

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