Non-Linear Architectural Design Process

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The introduction of the computer to the architectural design process have facilitated the possibility to examine a large number of design alternatives by allowing continuous variation between pre defined constraints. However, for the most part, evaluation and comparison of the alternatives is still handled manually in a linear fashion by the designer.

This paper introduces a different approach to the architectural design process, which calls for a multithreaded or a non-linear design process. In a non-linear design process design directions and alternatives are generated, presented and evaluated simultaneously, and in real time. As an example for a non-linear design process the Generative Performance Oriented Design model and software tool (GenPOD) are presented and discussed.

Moving towards non-linear modes of design arguably increases design creativity by allowing generating and evaluating a greater number and variation of design alternatives.

1. Introduction

Although architectural design processes ends up with a single built design, during the design process numerous design alternatives are generally created and evaluated. In traditional design, prior to the introduction of computers, examining several design alternatives meant that labor had to be dedicated to the creation of every singular design alternative. As architectural design is often performed under tight schedule and budget, the amount of resources designers have to investigate design alternatives is highly limited.

The shift to computer-oriented design introduced two main changes in this domain; the first change had to do with the increased ability and the ease of drafting, modeling and elaborating architectural forms, which allowed designers to increase productivity and thus able to examine more design alternatives faster. The second change, and the more important one in this context, has to do with the possibility to harness computer processing power to generate and evaluate design alternatives.

Early attempts in the 1970's to use computers to generate design alternatives tried to use computer power to generate architectural form in methods such as Complete Enumeration, which tried to generate all the permutations of basic design problems, and Space Allocation, which was used mainly in generation of building plans [1]. This line of research had, apparently, encountered substantial problems in dealing with complex 3-D design problems and was therefore abandoned. Later developments in this domain, promoted methods as Cellular Automata [2], Expert Systems [3], Case-Based Reasoning [4], Shape grammar and formal rule-based form generation [5] and evolutionary design [6], [7]. Some of these methods as evolutionary design promoted as well the generation of design alternatives. However, although found effective by some researchers for architectural and for structural engineering design [8], [9], none of these methods were embedded in architectural software and are not commonly used by architects in the state of the practice design process. This can be explained by the complexity of the architectural problem which cannot easily be translated to computer language, the singular nature of each problem – every building program is unique, new definitions of rules are necessary for each project and cost – working with code requires professional knowledge and training that, normally, is outside the scope of an average architectural practice.

Today, it is quite clear that entire building form generation and optimization, which is based on multi-criteria parameters, will not be possible in the near future. Hence, generation and optimization as a design tools should be redirected toward design exploration and the development of alternatives for the early stages of design. Being able to use and negotiate various solutions in a multi-solution form generation process in architecture will help to propel the move to "lateral thinking" in design as opposed to "vertical thinking" [10], a network or a rhizomatic mode of design rather than the traditional linear method [11].

This paper proposes a shift to a multithreaded or non-linear architectural design process in which several design alternatives can be simultaneously generated and evaluated, based on different performative and programmatic criteria. It discusses the main advantages of non-linear design compared to current linear design process. It then introduces as a case study a generative performance oriented design model and tool (GenPOD) in which a new non-linear design method is implemented.

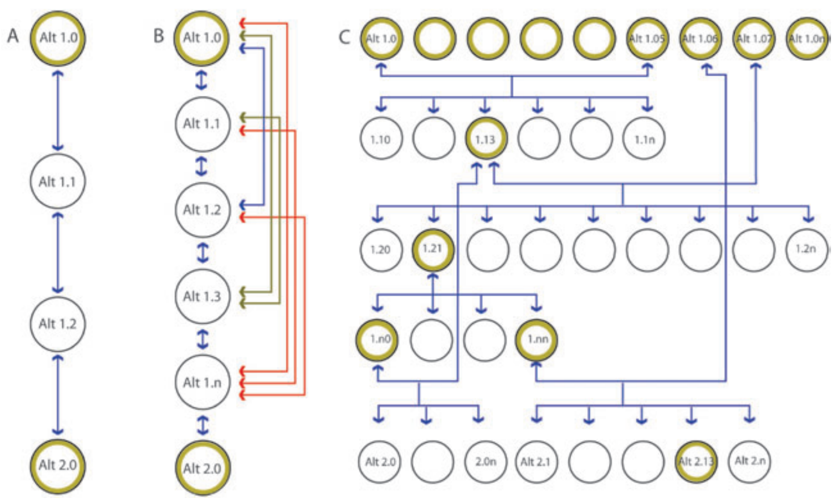
2. Gaps in linear modes of architectural design

The idea of alternatives in design is directly connected to the notion of evaluation. Having generated design alternatives the designer has to choose the most appropriate alternative according to certain fitness criteria. Generally, during the evaluation process intrinsic and extrinsic criteria are used. Intrinsic criteria refer to the evaluation of alternative's fulfillment of the parameters under examination. Extrinsic criteria, on the other hand, have to do with quantitative information on the form which does not have a direct connection to the parameters that were used to generate the alternative and qualitative, ill defined, aesthetical and visual criteria. For example, if one generates alternatives of architectural form in regards to thermal comfort, intrinsic criteria would be related to temperature, relative humidity, natural ventilation etc., and extrinsic criteria would refer to parameters such as total floor area, number of floors, envelope curvature and area, and a visual evaluation of the form.

Since every design problem is unique, the framework for the evaluation of the design alternatives has to be flexible enough in terms of choosing the specific fitness criteria (both intrinsic and extrinsic), examining the ramifications of various sets of fitness criteria and selecting the more relevant for each situation.

Current engagement in parametric design and BIM allows for design exploration mainly through continuous differentiation [12]. Architectural projects that have been designed using these methods argue for the possibility of using constraints to examine the entire scope of the design space. Examples for this approach are found in several projects by Foster + Partners [19] and in the Variomatic project and software tool by Oosterhuis[20]. Although this method allows exploration of numerous alternatives by controlling parametric continuous changes the designer has to work with two separate files, or to parametrically shift back and forth between alternatives of a single model, in order to qualitatively (visually) or quantitatively compare two or more alternatives. Employing this method in a single parameter design problem scenario would not be too complex. However, since design problems by nature are multi criteria, and both visual and quantitative evaluation is essential in all design stages, the lack of ability to effectively compare alternatives is a substantial disadvantage of this type of design process.

A comparison between traditional, parametric (BIM) and the possible non-linear design process is presented in Figure 1. The comparison examines the 3 different approaches to the design process concentrating on two design stages. The decision to examine the design process between two stages only is based on the understanding that albeit the theoretical possibility to modify the design until the very last stages (Figure 1, A and B), in real life design, one needs to freeze configuration at certain points during the design process [21]. Configuration freeze is common among the design process of other disciplines (such as aviation, car and naval). Thus, it may be argued that changes in a chosen design alternative beyond two design stages will occur only in small, specific parts of the building that would not influence the entire configuration, or under highly specific circumstances as in the case of a critical mistake in the design.



► Figure 1: Linear and non-linear design processes. A - Traditional design process. B - Parametric design process (continuous differentiation). C - Non-linear design process.

The main difference between the linear parametric design process (Figure 1, B) and the non-linear process (Figure 1, C), besides the obvious ability to generate and work with several design alternatives, has to do with the ability of the non linear algorithm to generate new alternatives deriving from both single and multiple initial alternatives. This allows the designer to combine successful alternatives from different sub-stages in the generation process (see for example the generation of alternative 1.21 from 1.13 and 1.07 in Figure 1, C).

The idea of multiple design solutions has been discussed widely in traditional design thinking and cognition discourse. Some examples are the discussion on parallel lines of thought by Lawson [13], the discussion on top-down and bottom-up approaches within the space problem by Rowe [14] and Alexander's procedural design method described in his seminal book "Notes on the Synthesis of Form" [15]. However, these approaches and methods still fall within the realm of linear design. Although the possibility to go back and forth during the design process (see Figure 1, A and B) is mentioned and discussed in these texts, they do not discuss nor mention the option of combining ideas from various stages of the design process as suggested in the non linear design process (Figure 1, C) . This can be explained by the connection of non linear design to computers, which were not widely used for design when these ideas were developed.

Although computational frameworks for design support systems, which engage with creative alternative-oriented design processes has been suggested in numerous academic studies in the past [16], [1], [17], none has been successful enough to be fully implemented by architects in design process. Moreover, this research did not trace the use of design decision-support systems by architects using custom or commercial architectural design tools.

The following section presents an effort to close the gaps in alternatives generation and evaluation that were described in this section by developing a design model and tool which are based on the generation and evaluation in real time of multiple design alternatives.

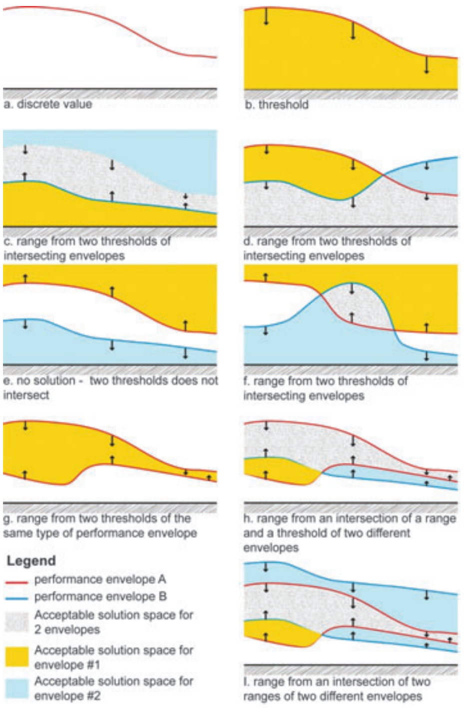
3. GenPOD model and tool

The GenPOD model and tool were developed for the generation of either an initial building's form or a design space of solutions that are based on several different performance aspects, in order to increase the overall performance of the designed building [18]. The model suggests the use of performance envelopes as a mean to generative performance oriented architectural form in a non linear architectural design process. Performance envelopes are surfaces that connect points with similar results regarding desired, obtained or required performance. Employing a discrete value envelope suggests that the envelope's surface can be used as an architectural form. Using a single envelope as a threshold defines a boundary for the solution space of the architectural form. A range type defines a space of solutions between two boundaries. Figure 2 presents a series of diagrams showing the various solution spaces that could be defined by different basic types of one or two performance envelopes.

Generating a building form from a single type of performance envelope is a straightforward process. It can be done using a discrete value, two types of threshold and a range (see Figure 2, A, B, G). In the first type of threshold, the closer the result to the threshold the better it is. In the second type all the points within the solution space, which is defined by the threshold itself, have the same fitness value in terms of the solution's quality. In this type of threshold and in a range condition, the designer has to employ additional fitness criteria in order to choose the most appropriate solution within the solution space (see Figure 2, B, G).

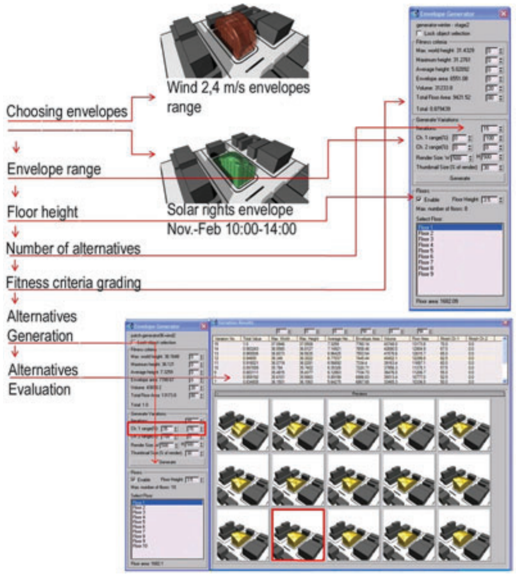
A multi-performance envelope scenario is much more complex. First, performance envelopes must have a common ground, be it full or partial, in order to be able to generate a solution space (Figure 2, C, D ,I) which complies with all the requirements. Another possible situation is a local intersection (see Figure 2 F, H), in which only a local solution is possible that complies with the two envelopes. In the zones where there is no intersection, the designer should use other performance envelopes or adhere to only a single performance. When the envelopes do not intersect or overlap, no common ground exists. In this case at least one of the envelopes must be redefined by adjusting the values of the performance used to generate the performance envelope (see Figure 2, E).

► Figure 2: Basic solution space from one or two performance envelopes.



It is clear that introducing more envelopes can lead to conflicts and negotiations, and increase the complexity of the route to the solution. Having more than one performance envelope necessitates a subjective decision by the designer regarding priorities and/or the employment of other external fitness criteria to be able to find an acceptable solution. Moreover, having a solution space implies that there is no one best optimal solution, allowing design freedom. The lack of a single solution suggests that we ought to think of a generation process that produces alternatives to be evaluated at a second stage rather than developing a single design in the traditional way.

In the generation process the GenPOD model uses a morphing algorithm that is capable of negotiating different performance envelopes surfaces to generate numerous design alternatives which are presented to the designer in a visual catalogue (see an example of a design process based on two performance envelopes in Figure 3).



◀ Figure 3: User interface, initial set up and generated alternatives visual interactive catalogue (the alternative with the highest grade in the current fitness settings is marked by a dark/red rectangle).

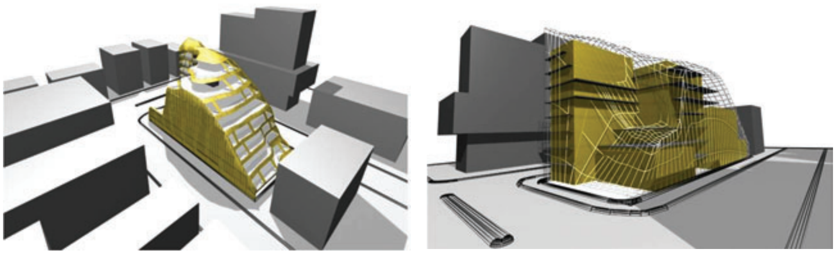
The generated forms in the suggested design model adhere by definition to the performances defined by the envelopes that were used to generate it, considering the negotiations done during the process. This can improve the general performance of the building form, save time in the design process, while producing a form that embeds higher amount of information from the very beginning of the design process.

The generation process ends when a satisfying solution is found. Nevertheless, this design method is open ended – it is possible at any given time during the generation process to go back and forth, erase secondary stages, change or introduce new performance requirements, change preferences and regenerate new solutions according to the brief. The final result can be used as a design space for further design development or as the actual buildings form (Figure 5).

The current model was examined so far only in the building scale. Nevertheless, it is expected to be applicable also for the urban and regional scales. In both scales the model would generate an environmental performance oriented 3-D envelope, which could be used as initial guidelines for urban designers and planners to developed urban or regional plans [22].

▶ Figure 4: Visual catalogue of generated alternatives. A-total grade, B-extrinsic criteria's values, C-deviation/adherence to performance envelope (intrinsic criteria), D-generated alternatives (the alternative with the highest grade in the current fitness settings is marked by a dark/red rectangle.

▶ Figure 5: Possible use of the selected envelope. Left: building's initial form; Right: design space



3.1. Non linear design process

The output of the generation process focuses on the exploration and definition of the designed space, rather than producing a single best solution. It allows the designer to define the number of alternatives that the generation process would create and the interval, in terms of changes in parameters, between the alternatives (see Figure 3). The number and variation of alternatives is to be related to the design stage and the expected difference between the alternatives. It is logical to assume that in the early stages of design, while different design direction are explored and there is a considerable difference between the generated alternatives many design alternatives would need to be generated. In later stages of the design, however, only a small number of alternatives would need to be generated and a small variation between them is expected.

Accordingly, alternatives can be generated and evaluated in any design stage for the entire building form and for parts of the designed form, while several design alternatives can be explored and developed at the same time.

3.2. Alternative evaluation and grading

The GenPOD model includes a grading algorithm which comprises both intrinsic and extrinsic criteria.

During the evaluation process a normalized grade is calculated for every single criterion and a total grade for every design alternative. The results of the generation and grading processes are presented to the designer in a visual interactive catalogue (see Figure 4). The total grade is calculated by using the designer input regarding the weight of each fitness criteria (in a 0-100 scale) in the specific evaluation (see A and the upper part of B in Figure 4). The weight can be altered by the designer in real time to examine the effect of different sets of criteria on the total grade.

To facilitate an interactive examination of various grading scenarios, the interface also allows changing the level of influence of every criterion after the initial generation of alternatives. This can change the grading of the various alternatives and may change the alternative that receives the highest score, thus leading the designer to modify his decision about the selected solution.

Two types of criteria are implemented in the current model:

- Examination of the way the form adheres to the performance criteria used to generate it (intrinsic criteria). This assessment is done both intrinsically by reading the level of adherence to each initial performance envelope and visually by evaluating the results using the visual catalogue. In order to determine the exact compliance with the performance requirements, an embedded simulation or connections to external simulation tool is needed. This could not be done within the current tool, which was developed in the frame of 3D MAX software that does not offer exact simulation modules.
- Information on the geometry and dimensions of the generated form (extrinsic criteria). The fitness criteria that were used: maximum world height (the distance from the lowest to the highest point), maximum height (from the building 0 level), average height, envelope's area, envelope's volume, floors division, area calculation and total floor area.

4. GenPOD and BIM

The following table presents the current GenPOD model in comparison to a typical BIM software:

	Generation of Design alternatives	Number of Alternatives	Alternative Evaluation/Grading	Embedded simulation capabilities
Typical BIM software	-	-	-	In some tools
GenPOD tool	+	User defined	+	-

▲ **Table 1: Comparison between the current GenPOD model and typical BIM software.**

The table shows that in terms of design exploration the GenPOD model offers many advantages. However, since the tool was developed in a commercial design tool environment, the main drawback of the current GenPOD model in comparison to models that are developed within BIM environment is the lack of possibility to embed simulation models. Embedding simulation models in the next version of GenPOD would allow this tool to combine extrinsic with intrinsic fitness criteria evaluation in real time.

5. Conclusions

The shift from linear to non-linear parametric design method seems to have great potential for increasing the creativity and performance of designs, fine tuning design solution to a brief, and corresponding with the aims of the designer. Although the suggested model and tool are only the initial steps in the way towards a new paradigm of non-linear design, it has clearly shown the potential and applicability of the new approach.

Non linear design does not promote a formalist trend, nor does it furnish a new style or set of meanings. Its main strength rests in the embedded possibility for designers to both generate and evaluate large number of architectural design alternatives using a combination of empiric, quantitative and qualitative fitness criteria.

However, a shift to a non-linear paradigm does not have to be itself linear. The suggested non-linear design approach does not negate other approaches to design but adds another dimension to an increasingly pluralistic palette of architectural design methods.

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