

Performance Based Form Generation in Architectural Design - Using Performance Envelopes in a Generative Computer Oriented Design Method

XXX XXX*, XXX XXX, XXX XXX

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* xx@xx.xxx.xx.xx

Abstract

The use of multiple performance envelopes in a generative, non linear architectural design process is discussed. A Generative Performance Oriented Design model (GenPOD) which allows generating architectural initial form using a negotiation morphing process of several performance envelopes is presented. The suggested form generation process is parametric and iterative. It allows numerous rounds of generation using different performance envelopes. It suggests a method that allows combining information on various types including quantitative performances, programmatic demands and designer's preferences in an integral generative process that influence selected parts or the entire generated architectural form.

The GenPOD model is demonstrated by a practical design case study scenario of an office building. It argues that since the initial form is generated using performance envelopes it adheres by definition to the performances that were used in its generation process and does not necessitate an "after the fact" performance simulation and evaluation processes. Therefore a form that was generated in this process embeds a higher level of information on performance aspects.

Keywords: Performance envelopes, Generative design, Performance Oriented design, Computer Oriented Design, Fitness criteria

1. Introduction

Decisions made during early stages of the design process have a profound implication on the achieved performance of the designed building. Many contemporary design processes in architectural practices use simulation results in an "after-the-fact" manner for evaluation purposes. In this kind of design process, the design solution's adherence to performance criteria is examined using simulation software and modified according to the results in order to improve upon it. However, changes at the late design stages are generally very limited, hard to implement and expensive. This work proposes using multiple performance envelopes in a generative or "before-the-fact" manner, that is, to generate a 3D design space or a building's initial form that embeds performance requirements from multiple performance envelopes. In this way, the generated form adheres by definition to the performances defined by the envelopes that were used to generate it. This can augment the general performance of the building form and save time in the design process, while producing a form that embeds a larger amount of information.

2. Using Performance Envelopes in the Design Process

Performance envelopes are surfaces that connect points with similar information 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 solution space between two boundaries. Figure 1 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 1 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 other fitness criteria in order to choose the most appropriate solution within the solution space (see Figure 1 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 1 c, d, i) which complies with all the requirements. Another possible situation is a local intersection (see Figure 1 f, h), in which only a

local solution is possible that complies with the two envelopes. In the areas 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 changing the values of the performance used to generate the performance envelope) (see Figure 1 e).

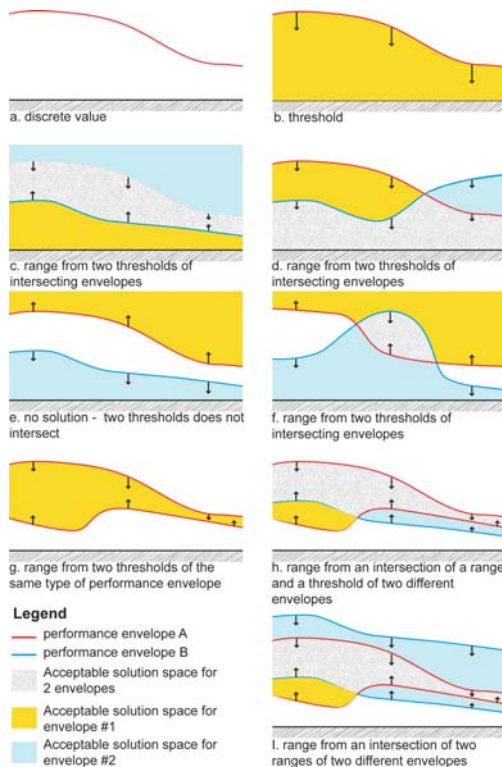


Fig 1. Basic solution space from one or two performance envelopes

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 a 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.

Different performance aspects have been identified according to the possibility of quantifying and using their performance as a generative trigger: sun shading/exposure [1][2], wind, acoustics, visibility/lines of sight [3][4][5], circulation, structure and energy consumption.

3. Generative Performance Oriented Design (GenPOD) Model

The GenPOD model main aim is the generation of an initial building's form or a design space that combine several different performance aspects in order to increase the overall performance of the designed building. It uses a morphing algorithm that is capable of negotiating different performance envelopes surfaces. The morphing algorithm calculates the weighted average point in space between any two points/surfaces according to a, designer defined, level of influence of each performance envelope surface. It also generates several alternatives which are then assessed and graded using a parametric grading algorithm, according to 3 different types of fitness criteria:

a. Examine the way the form adheres to the performances used to generate it. This assessment is done visually by the designer. The starting point of the suggested generation process offers adherence to the performance used as envelopes. However, in order to determine the exact compliance with the requirements an external simulation tool has to be used.

b. Adherence to qualitative performances that are connected to perceptual and cognitive aspects. This type has also to be evaluated visually by the designer.

c. Information on the geometry and dimensions of the generated form. This type of information could have influence on the designer preferences regarding the general evaluation/preference of the form as it can affect the building cost and adherence to the brief.

In order to examine the applicability of the model for the last type of assessment, several fitness criteria were used. Amongst them we can mention the following: maximum world height (the distance from the lowest to the highest point), maximum height (from the building's 0 level), average height, envelope's area, envelope's volume, floors division, area calculation and total floor area. Nonetheless, it is clear that the complexity and diversity of design problems will require the development of additional fitness criteria. Following a designer's decision regarding the height of a typical floor an area value for each floor and a total expected floor area are calculated and displayed. Also, according to the defined floor height the maximum possible number of floors is shown. The information on the expected/maximum floor area of a building is one of the leading considerations in developing design alternatives since it has large effect on the building cost and profit.

Since every design problem is unique the interface for the evaluation of the design alternatives has to be flexible enough in terms of choosing the various fitness criteria, selecting the more relevant for each situation.

A normalized grade is calculated for every single criterion and a total grade is given for every alternative. The results of the generation and grading processes are presented to the designer in a visual interactive catalogue (Figure 2).

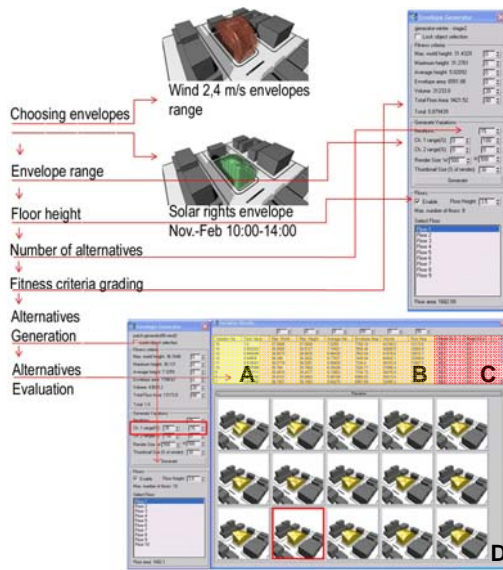


Fig 2. Initial set up and generated alternatives visual interactive catalogue. A-total grade, B-individual criteria's values, C-deviation/adherence to performance envelope, D-generated alternatives (the alternative with the highest grade in the current fitness settings is marked by a dark/red rectangle)

Since GenPOD is a parametric model and in order to facilitate an interactive examination of various grading scenarios it is possible to change the level of influence of every criterion also after the initial alternatives generation. This operation can change the grading of the various solutions and may change the alternative that receives the highest score thus modifying the designer decision making.

Hence, GenPOD allows setting the level of influence of each generative channel (i.e. each performance envelope) so in some cases one envelope may lead the preferred alternatives upon others.

4. Case Study - Implementation of the Genpod Model in the Generation of an Office Building

The purpose of the case study is to examine the GenPOD model that uses several empirical performance envelopes' data to either generate an initial design form or a solution space.

The site chosen is an empty plot located in Alenbi Street, which is one of the main commercial and business streets in Tel Aviv.

4.1 Constraints definitions

Constraints were defined regarding two aspects. The building itself and the performance envelopes to be used in order to reach a formal solution.

4.1.1. Building's brief

The building will add minimal shade on the commercial and residential buildings around the site in winter time, being it the critical period in terms of solar rights and sun radiation in Tel Aviv. Therefore the solar rights envelopes were defined between November and February from 10:00 am

to 14:00 pm. Shade might be added in summer by means of dynamic shading devices.

The building form and position will allow maximum natural ventilation in the open public areas within the limits of comfort during the main working hours. Specific attention should be given to the building's entrance where wind velocity should be minimized - no more than 2 m/s desirable for thermal comfort reasons (for reference about wind effects and comfort scale limits see [8]).

d. The building's form should offer maximum floor area in order to gain the highest renting revenue.

4.1.2. Performance envelopes

Three types of performance envelope were initially considered for the case study:

Solar envelopes - The solar rights and solar catch envelopes used for the case study were defined according to the building's brief requirements. They were imported from simulations performed using the SUSTARC model [9].

Wind envelopes - Wind velocity envelopes were generated using the ENVI-met 3.0 software [6]. The climatic input data for the simulation was taken from the Climatic Atlas of Israel [7]. Five envelopes (from 1 to 5 m/s) were generated by employing the typical wind regime in the site for both summer and winter periods. The influence of wind during summer period was treated according to the Building Research Establishment requirements [8]. According to these definitions, average wind velocity of 4 m/s is recommended in order to reach thermal comfort in open spaces for short-time exposures. It is just below the agreeable wind speed limit which is less than 6-8 m/s. It also allows natural ventilation for thermal comfort inside the building without disturbing the activities to be performed there. Higher wind speeds, which could allow better ventilation, can be considered for spaces that are not inhabited or cooling the thermal mass. In places that are designed for longer exposure to wind as balconies, roof terraces and entrances a light breeze or light air is appropriate (wind speeds between 1 to 2 m/s). Therefore, we related in the case study to 4 m/s wind performance envelope as the upper threshold and 1 m/s, 2 m/s wind performance envelopes as lower threshold.

4.2 Form Generation

4.2.1. Initial Generation and evaluation process

The initial setup was based on the demands presented in the brief regarding wind and shade conditions. The initial performance envelopes are generated using data from context and programmatic demands. After verifying that the generated performance envelopes have common grounds an initial set up is performed. The data needed in this stage consist of basic fitness criteria, the specific range of the each morphing channel, the height of each floor and the number of alternatives that the generation process should generate.

As an initial step it was decided to generate 15 initial alternatives and use the entire range of the morphing channel. The results of the initial

generation showed a big difference in terms of floor area, volume and envelope area between the alternatives.

The floor area and number of floors varied from 9 floors in the smaller alternative up to 11 floors in the larger alternative (which contradict the brief's limits). Moreover, the deviation from the solar rights envelope in several alternatives (below 35% and above 70% of the generation channel, i.e. the level of influence of each performance envelope) would have cause shade in more than the first 2 floors of some of the surrounding buildings which stands against the initial brief.

Therefore, it was decided to narrow the generation channel to 35%-70% (Figure 2).

The evaluation of the results of the second generation round consisted of three types of criteria.

The first type examined the number of floors and the expected floor area of each alternative. It was noticed that starting from alternative 10 the building volume could be divided to 10 levels instead of the 9 possible levels division of the other alternatives. From those alternatives that support 10 levels division only alternatives 12 and higher allow floor area of more than 300 m² in the 10th floor. The second type of criteria included the general grading (total value) that was calculated. From the different variations that were generated, alternative number 15 received the best score (1.0), having also the highest results in all the criteria. Therefore, changing the fitness criteria ratios between different criteria will change the final grade but will not change the position/hierarchy of the alternatives in the score table. It was also noticed that there was slightly higher difference between the grades in alternatives 12 and 11 (about 0.3 against to 0.15-0.2). This difference can be explained by the jump in floor area which is about 300 m² between all consecutive alternatives except 11 to 12 were it jumps to 619 m² (Figure 2).

The third type of evaluation criteria was performed visually and involved aesthetics and visual comparison to the initial performance envelopes. The evaluation showed that alternatives 11 and 12 have the greatest potential in terms of their minimal deviation from both wind (2 m/s) and solar right envelopes and the simplicity of the form. Following these results alternative 12 was selected to be further developed in the next stages (Figure 2).

4.2.2. Local generation/optimization process

Local generation applies on a certain portion of the form the same process that was described in the previous stage. One of the main aims of this stage in terms of the design process is to refine the selected alternative according to local conditions and examine performance information from new performance envelopes. In the presented case study two local generation process are demonstrated:

a. The first one concentrates on the local area facing the commercial Streets, where the entrances of the building are planned. It utilizes

1m/sec wind velocity performance envelope. The first step in local generation is to select the area that will be affected by the local re-generation process. The definition of the local area is based on a subjective preliminary design decision that the commercial area facing the street in the new building has to be around 20 m² and have double floor height. Nevertheless, it is possible to easily examine the implication of any other area definition simply by performing another generation run.

In order to differentiate between the results of the local generation two subjective design decisions were taken. The first was to search for a solution that will allow two double height stories in the entrance area in order to fit a future commercial use at street level. The second decision was to look for a solution that maximizes floor area in the upper floors of the future building. Examining the generated forms pointed out that only one alternative offered the two needed commercial floors while partially embedding the local envelopes constraints. In the others the entrance area was either too low and did not allow double height commercial floors or too high which was too close to the starting form where the wind velocity at the entrance level was too strong, beyond the required limits.

b. The second local generation will be applied to fine-tuning a selected area located at the southern part of the building. It will show the possibility to use more than one performance envelope in a local generation process.

Following the area selection, local generation that utilizes solar rights envelope was performed. The solar rights envelope that was used kept the solar rights of the surrounding building according to the definitions of the brief. The criteria used to evaluate the results were the floor area (which was expected to decrease), the adherence to the envelopes (examined visually) and building envelope area.

Alternative number 9 was chosen (Figure 3). This alternative has the third largest floor area (10183 m²) after alternatives 1 and 2 (10273 and 10263 m² respectively). However, alternatives 1 and 2 show a smaller effect in the new envelope (0% and 7.1% influence in comparison to 57.1% in alternative 9), thus is much closer to the desired performance at the designated area. In terms of an evaluation that combines floor area and envelope area (defining 50% influence for each criterion) alternative 9 has also the 3rd best grade (0.98) very close to alternatives 1 and 2 (1.0 and 0.99). The case study brief is not detailed enough to decide whether this gap is big enough to stop the generation process at this stage, or, another local generation round is needed in order to make the final result more substantial in terms of the difference from other results. Nevertheless, the fact that the proposed design process is parametric suggests that it is possible at any time to add and subtract local and global form generation processes using various types of performance envelopes.

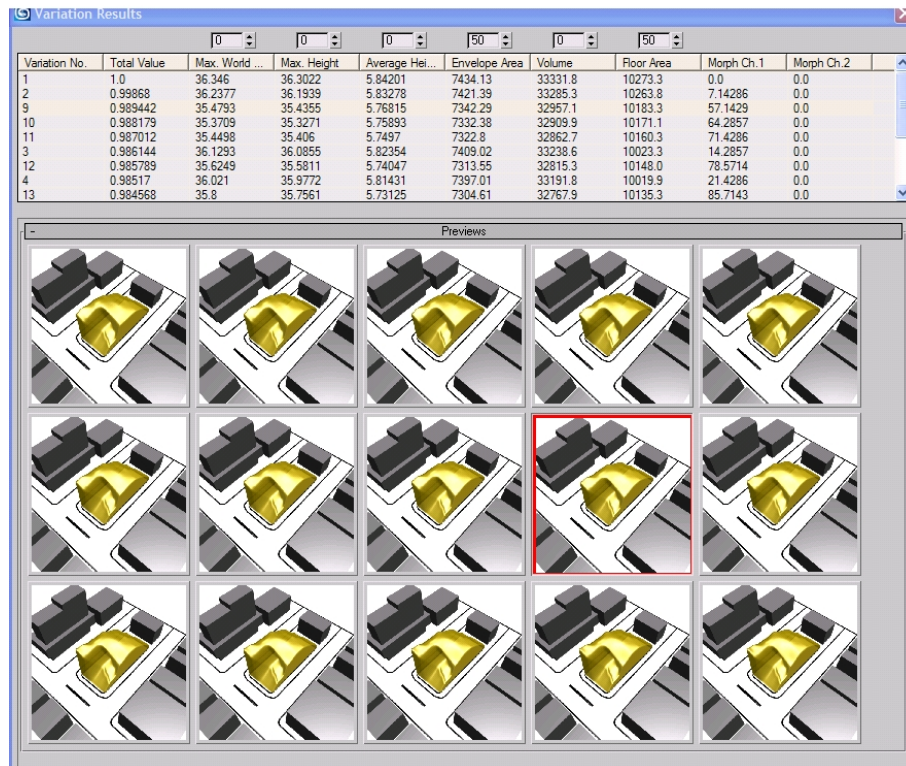


Fig 3. Final alternatives generation

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, 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 4)

4.3 Results evaluation

A results evaluation is performed in this case study to prove that generated form adheres to the performance requirements of the Constraint Definitions. Since the form is actually generated from performance envelopes it is expected that evaluation stage would not be necessary while using this model for design in the future. The case study results evaluation inspects the alternative's adherence to solar rights and wind performance envelopes that were used to generate the solution. A quantitative evaluation of the selected alternative regarding solar rights impact was performed by comparing the sun exposure of the surrounding facades with and without the new building. The evaluation was done using the SHADING model that calculates the Geometrical Insulating Coefficient (GIC), which is the ratio between the insolated and the total surface area of the building facades [9]. The results showed that the situation before and after the building's design proposal on the site in terms of the sun direct radiation and shade conditions in the designated period differs as follows (see Figure 5): East facades - after

around 12am the facades are self shade in all the examined period. From 10 am -11 am there is around 10% change in shade and from 13 pm-14 pm the change grows to around 20%. South facades - in October and February the difference is close to 0%. In November and January the difference is around 15% and in December the difference is around 25%. West facades - until 11 am the facades are self shaded in all the examined period. Between 11 am-13 pm there is nearly no change, between 13 pm and 14 pm there is 0-5% additional shade.

These results demonstrate that the generated form closely adheres to the demands of the brief. The minor change in the amount of radiation in some of the facades between the initial situation (without the building) and the proposed situation can be explained by the fact that several performance aspects influenced the examined form's generation.

The evaluation of wind velocity was done in ENVI-met 3.0. Since this software does not support importing 3-D complex models an approximate version of the final result was used. The results of the simulation results are presented in Figure 5.

According to the results wind velocity envelopes of 1, 2 and 4 m/sec are very close to the initial envelopes used for the generation and generally follow the building volume. Both entrance areas have 1-2 m/s wind velocity which do not deviate from the brief and create comfortable access to the building. Also, the building's form does not deviate from the 4 m/s envelope and it follow its general form. However, small deviations occur at the upper areas of 1 m/s and 2 m/s envelopes. It

is reasonable to assume that these deviations are caused by inaccuracies in the simplified model and the fact the envelope is highly curved in these areas. This fact should be taken into consideration in terms of the level of confidence in the evaluation results in this area.

5. Conclusion

The GenPOD model introduces the notion of multiple performance envelopes as a generative design tool. The suggested model facilitates designers with a numeric parametric control of environmental and programmatic fitness criteria in the initial form generation process. It also provide designers a higher level of control over the design's form by allowing immediate visualization of changes and their causes in different ratios of both single and multiple fitness criteria scenarios. The generated form in the suggested design method adheres by definition to the performances defined by the envelopes that were used to generate it. 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 presented process generates many design alternatives from which the designer can compare, learn and choose the best one according to several types of fitness criteria. The fact that this process is parametrically controlled makes it possible to modify at any time every input value, which will accordingly change the result.

The case study demonstrated the possibility to negotiate multiple different performance envelopes in an architectural design form generation process. It also demonstrated the possibility to use performance envelope to modify local areas in the developed solution.

The case study exhibited the possibility of designers to use interactive empiric fitness criteria as part of the design creative process. The new approach for grading helps designer to evaluate both quantitatively and qualitatively the generated forms comparing different scenarios of fitness criteria.

6. References

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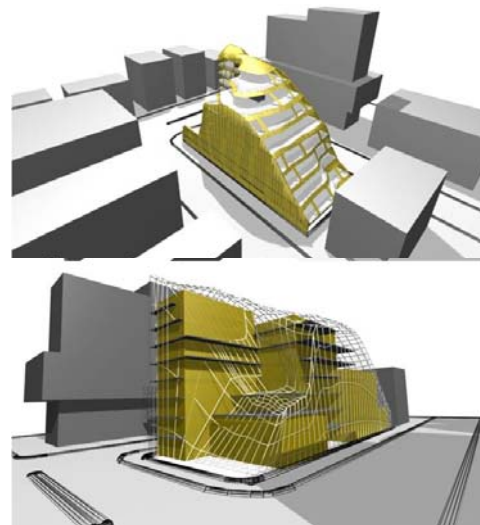


Fig 4. Possible use of the selected envelope. Top: building's initial form; Down: design space

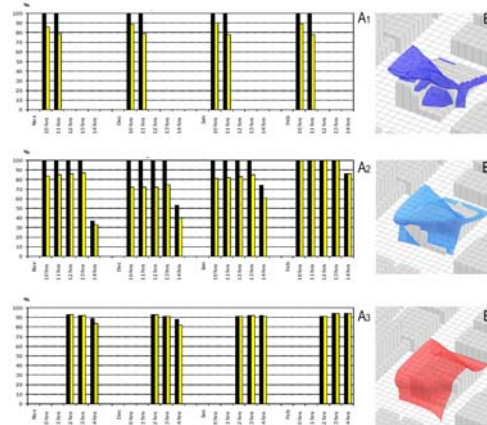


Fig 5. Case Study Evaluation. Left: Solar exposure. Quantitative evaluation with and without the new design proposal (results with the design proposal are shown in light/yellow). A1) East façade; A2) South façade; A3) West façade; Right: Wind velocity. Right Wind 1, 2, 4 m/s envelopes with the new design proposal.