# A COMPUTATIONAL SYNTHESIS OF HIGH PERFORMANCE ARCHITECTURAL PRIMITIVES

KAUSTUV KANTI DE BISWAS
Bachelor Of Architecture,
Department Of Architecture
Jadavpur University, INDIA

Advisor Information
GOURABMOY NATH, PhD.
PROF.SOMEN CHACKROBORTY

*This paper investigates the possibility of obtaining optimum design solution at the early conceptual stages of design, by formulating a synthesis/generative approach based on an optimizing structure. The generative system (GS), consisting of a search process based on Genetic Algorithm and simple simulation procedures, generates possible design solutions for a given site by optimizing the design criteria. The design of climatologically (Heat, Light and Wind) high performance forms in Kolkata is used as a test bed. The objective functions have been simplified in order to allow a quicker and wider search, (a larger population with a larger number of variables) which is desirable in early stages of design.*

*Not only does a comparative analysis suggest that the solutions obtained using this GS are superior starting points for design than the ones conventionally used, but the process also brings transparency into the system. Even if one deviates from the optimised benchmark, an objective evaluation of the compromise or deviation can easily be done. Starting of from an optimised benchmark at the intuitive stage gives one the greatest potential for improving on performance efficiencies and environmental economies as it becomes significantly more difficult and costly to allow any changes at a later stage in a project's development.*

## INRODUCTION

Aladar Olgay, in his report on the climate of Kolkata (early 1980s), had suggested optimum orientations to help architects but nothing was said about the building form. Only broad climatological rules are available to designer during the early conceptual stages of design. In Kolkata the general rule that is available for reducing heat gain and increasing light and air flow is as follows:

1. Reduce East - West facades.
2. Increase fenestration in the North - South facades.
3. Reduce surface to volume ratio (compactness)

The solutions intuitively obtained by following this basic grammar are better than generic shapes(square,octagon) in climatological terms (refer comparative analysis) but there exists no formal guidance to designers based on precise calculation. The conventional intuitive solutions can greatly be improved by available evaluation software but these solutions obtained by a trial and error method cannot be proven to be optimum.

This paper investigates the possibility of a true optimum by using an optimization structure based on a Genetic Algorithm (GA). GA was chosen as a search mechanism because of its suitability to the architectural design context because its output is not a single solution but a number of high performance solutions, one or more of which the architect can further develop by considering other criteria not included in the search. (Caldas and Norford, 2001).

## GENETIC ALGORITHMS

Genetic algorithms are a search method based on the mechanisms of natural selection and the notion of evolution. They consist of some type of population (such as candidate solutions to a problem), some method of selection (such as an exogenous fitness calculation), and operators (such as crossover and mutation) which transform one population into another. In normal GA we take a population of genomes (candidate solution) randomly scattered across and evaluates the fitness of the results. The best are then retained (selection) and a new population created (reproduction), incorporating mutation and crossover operations to gain a different set of possibilities (variation). Over many generations the population will search state space and hopefully converge on the best solution, the global optimum. In multi-objective genetic algorithms we do much the same, except that in this case we are trying to optimise not for one parameter but against a collection of them. To achieve this we must generate an understanding of the overall fitness of the set of objectives, so that we can compare solutions. (Chris Lucas, 2000)

## OBJECTIVES

Kolkata (23.5$^{o}$LAT 88.3$^{o}$ LON) has a very hot humid climate during summers and this lasts for around 8 months of the year. In summer conditions temperatures soar as high as 40C. Winters are much more comfortable with temperatures hovering around 10C. It is mainly the cold winter winds that cause some concern. In summer reducing heat gain and increasing light and wind are desirable objectives. If independently dealt with, they would lead to contradictory structures. To reduce heat we need a heavy weight structure, increasing light would ask for a transparent structure while increasing winds would mean an open structure. The challenge would be to find out this elusive balance.

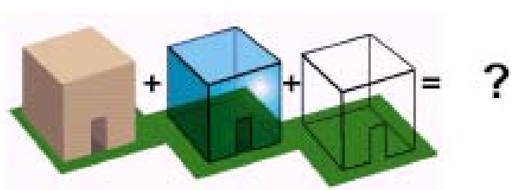


figure 1

## SIMULATION PROCEDURES

In order to reduce the complexity of the problem we have restricted our selves to simple steady state methods of evaluation. The intention of this paper is not to accurately simulate real conditions (like indoor temperature, lux conditions, wind velocity) inside the architectural forms, rather to relatively compare the response of parallel designs in terms of the given criteria.

Parameter HEAT: (For notations refer Pg4, Pg6)

$$\text{Heat Gain} = A_{wall} \times U_{wall} \times (T_o - T_i) + A_{wall} \times U_{wall} \times (I \times a)/f_o + 13/36 \times Vel_{wind} \times A_{win} \times (T_o - T_i) + \sum A_{win,j} \times I \times \oint_j$$

Parameter LIGHT: (For notations refer Pg4, Pg6)

Since there was no requirement for the calculation of actual light levels (considering intra-surface reflections), advanced radiosity methods have been avoided. A simple daylight factor method is used to compare the different forms.

$$\text{Average light level} = \frac{\text{Lux condition} \times \sum \text{Sky} \times A_{win,j} \times \oint}{2A(1 - R)}$$

Parameter WIND:(For notations refer Pg4,Pg6)

CFD calculations are complex and have been avoided. Instead a simplistic model of Air change rate has been implemented.

$$\text{Air Change Rate} = \frac{Vol_{zone}}{\sum A_{win,j} \times \text{transmission coeff} \times Vel_{wind}}$$

$Vel_{wind}$ is the velocity of the wind in the direction of the window j for a particular time of the year. Essentially the forms with larger windows in the direction the desirable winds is given a higher rating than others. Also larger window in the direction of the undesirable winds in give a negative credit.

## METHOD

The following steps were followed in the investigation.

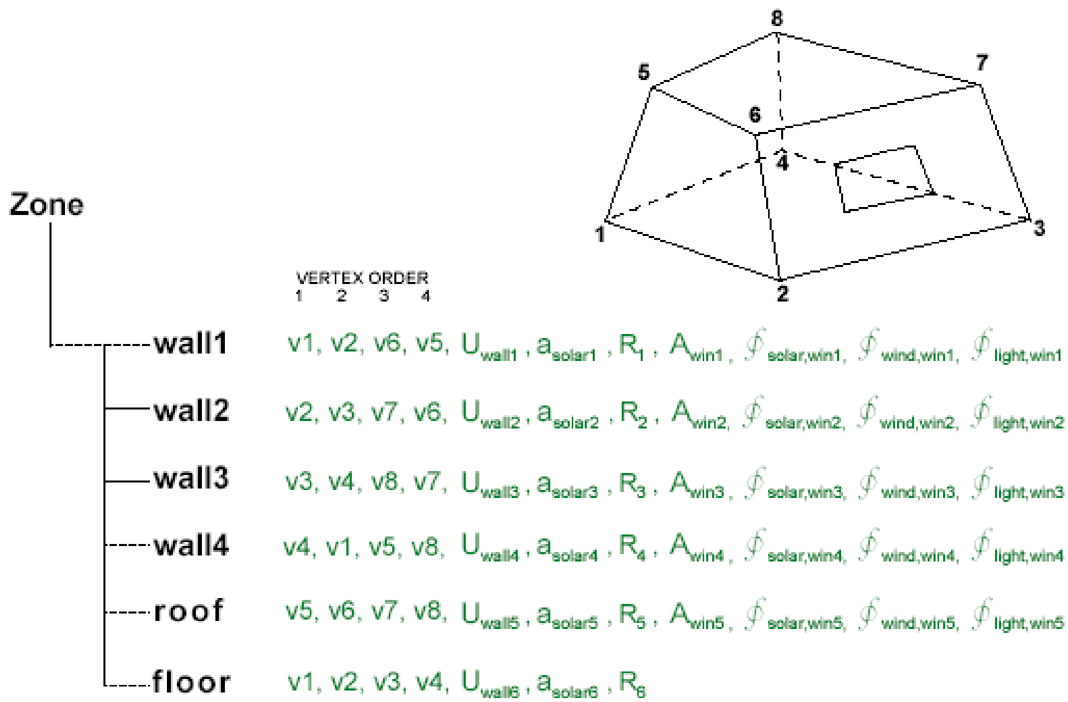
1. Define objective functions
2. Fix the mathematical representation of the design solution. (Creating the structure of the Genome)
3. Create a mathematical framework for assessing the fitness of the solutions
4. Run the Multi Objective Optimisation procedure
5. Obtain a pareto set. (non dominated solutions)
6. Intuitively scan the set to choose the appropriate solution or use a “decision maker” to reach the solution.

1. DEFINE THE OBJECTIVES AND ADD WEIGHTS

We did a survey in Kolkata in regard to the relative importance of the given objectives for indoor comfort and the following was established.

| | |
|---|---|
| Objective : reducing summer HEAT | Weightage: 84.1 |
| Objective : increasing summer WIND | Weightage: 75.8 |
| Objective : increasing summer DAYLIGHT | Weightage: 23.3 |
| Objective : increasing winter HEAT | Weightage: 39.1 |
| Objective : reducing winter WIND | Weightage: 47.5 |
| Objective : increasing winter DAYLIGHT | Weightage: 45.1 |

2. REPRESENTATION OF THE BUILT FORM.




Subject to,

$v_n$ vertices, it is of the form $(x_1,y_1,z_1)$ .....$(x_8,y_8,z_8)$ search space :

(x,y,z) must be a point within the allowable builtup volume.

$U_{wall\ n}$ U value for wall n ( search space: 0.85 - 7.50 )

$a_{solar\ n}$ Solar absorbtion coeff.for wall n ( search space: 0.10 - 0.95 )

$R_n$ Reflectance for wall n ( search space: 0.05 - 0.75 )

$A_{win\ n}$ Area of opening associated with the $wall_n$ ( search space: 0 - 95% of wall area )

$\oint_{win\ n}$ Window transmission factors for window ( search space : 0.04 - 0.83 )

The optimisation problem is formulated as follows:

Let the building form be represented in the form of a vector with the following variables,

$$B(v1..v8, U_{wall1}..U_{wall6}, a_{solar1}..a_{solar6}, R_1..R_6, A_{win1}..A_{win5}, \oint_{solar,win1}..\oint_{solar,win5}, \oint_{light,win1}..\oint_{light,win5}, \oint_{wind,win1}..\oint_{wind,win5})$$

To find optimum **B** satifying the following objectives:

1. minimize summer heat.
2. maximise summer wind.
3. maximise summer daylight.
4. maximise winter heat.
5. minimise winter wind.
6. maximise winter daylight.

2. MATHEMATICAL FRAMEWORK FOR RATING THE FORM (FINDING FITNESS VALUE)

First we need to assess the response of the form to the parameters considered in terms of the defined mathematical representation.

### Parameter :: Heat

$$
\begin{aligned}
\text{Heat Gain} = \; & \mathbf{0.5(xsum_1^2 + ysum_1^2 + zsum_1^2)^{1/2}} \times U_{wall1} \times \{(T_o - T_i) + (I \times a_{solar1})/f_o\} \\
& + 13/36 \times Vel_{wind} / \oint_{wind,win1} \times A_{win1} \times (T_o - T_i) \\
& + A_{win1} \times I \times \oint_{solar,win1} \\
& + \mathbf{0.5(xsum_2^2 + ysum_2^2 + zsum_2^2)^{1/2}} \times U_{wall2} \times \{(T_o - T_i) + (I \times a_{solar2})/f_o\} \\
& + 13/36 \times Vel_{wind} / \oint_{wind,win1} \times A_{win2} \times (T_o - T_i) \\
& + A_{win2} \times I \times \oint_{solar,win2} \\
& + \mathbf{0.5(xsum_3^2 + ysum_3^2 + zsum_3^2)^{1/2}} \times U_{wall3} \times \{(T_o - T_i) + (I \times a_{solar3})/f_o\} \\
& + 13/36 \times Vel_{wind} / \oint_{wind,win3} \times A_{win3} \times (T_o - T_i) \\
& + A_{win3} \times I \times \oint_{solar,win3} \\
& + \mathbf{0.5(xsum_4^2 + ysum_4^2 + zsum_4^2)^{1/2}} \times U_{wall4} \times \{(T_o - T_i) + (I \times a_{solar4})/f_o\} \\
& + 13/36 \times Vel_{wind} / \oint_{wind,win4} \times A_{win4} \times (T_o - T_i) \\
& + A_{win4} \times I \times \oint_{solar,win4} \\
& + \mathbf{0.5(xsum_5^2 + ysum_5^2 + zsum_5^2)^{1/2}} \times U_{wall5} \times \{(T_o - T_i) + (I \times a_{solar5})/f_o\} \\
& + 13/36 \times Vel_{wind} / \oint_{wind,win5} \times A_{win5} \times (T_o - T_i) \\
& + A_{win5} \times I \times \oint_{solar,win5}
\end{aligned}
$$

**Parameter :: Wind**

$$\text{Air change rate} = \frac{\begin{aligned}1/6\big(& x_{11}.xsum_1 + y_{11}.ysum_1 + z_{11}.zsum_1 \\ &+ x_{21}.xsum_2 + y_{21}.ysum_2 + z_{21}.zsum_2 \\ &+ x_{31}.xsum_3 + y_{31}.ysum_3 + z_{31}.zsum_3 \\ &+ x_{41}.xsum_4 + y_{41}.ysum_4 + z_{41}.zsum_4 \\ &+ x_{51}.xsum_5 + y_{51}.ysum_5 + z_{51}.zsum_5 \\ &+ x_{61}.xsum_6 + y_{61}.ysum_6 + z_{61}.zsum_6 \big)\end{aligned}}{\begin{aligned}& A_{win1} x \oint_{wind,win1} x\ Vel_{wind} + A_{win2} x \oint_{wind,win2} x\ Vel_{wind} + A_{win3} x \oint_{wind,win3} x\ Vel_{wind} \\ &+ A_{win4} x \oint_{wind,win4} x\ Vel_{wind} + A_{win5} x \oint_{wind,win5} x\ Vel_{wind} + A_{win6} x \oint_{wind,win6} x\ Vel_{wind}\end{aligned}}$$

**Parameter :: Light**

average light level =

$$\frac{\text{Lux condition} \ X \ \begin{aligned}\big(& sky_1 \ x \ A_{win1} x \oint_{light,win1} + sky_2 \ x \ A_{win2} x \oint_{light,win2} \\ &+ sky_3 \ x \ A_{win3} x \oint_{light,win3} + sky_4 \ x \ A_{win4} x \oint_{light,win4} \\ &+ sky_5 \ x \ A_{win5} x \oint_{light,win5} + sky_6 \ x \ A_{win6} x \oint_{light,win6}\big)\end{aligned}}{\left[\begin{aligned}&(xsum_1^2 + ysum_1^2 + zsum_1^2)^{1/2} \\ &+(xsum_2^2 + ysum_2^2 + zsum_2^2)^{1/2} \\ &+(xsum_3^2 + ysum_3^2 + zsum_3^2)^{1/2} \\ &+(xsum_4^2 + ysum_4^2 + zsum_4^2)^{1/2} \\ &+(xsum_5^2 + ysum_5^2 + zsum_5^2)^{1/2} \\ &+(xsum_6^2 + ysum_6^2 + zsum_6^2)^{1/2}\end{aligned}\right] \left[1 - \frac{\begin{aligned}&R_1(xsum_1^2 + ysum_1^2 + zsum_1^2)^{1/2} \\ &+R_2(xsum_2^2 + ysum_2^2 + zsum_2^2)^{1/2} \\ &+R_3(xsum_3^2 + ysum_3^2 + zsum_3^2)^{1/2} \\ &+R_4(xsum_4^2 + ysum_4^2 + zsum_4^2)^{1/2} \\ &+R_5(xsum_5^2 + ysum_5^2 + zsum_5^2)^{1/2} \\ &+R_6(xsum_6^2 + ysum_6^2 + zsum_6^2)^{1/2}\end{aligned}}{\begin{aligned}&(xsum_1^2 + ysum_1^2 + zsum_1^2)^{1/2} \\ &+(xsum_2^2 + ysum_2^2 + zsum_2^2)^{1/2} \\ &+(xsum_3^2 + ysum_3^2 + zsum_3^2)^{1/2} \\ &+(xsum_4^2 + ysum_4^2 + zsum_4^2)^{1/2} \\ &+(xsum_5^2 + ysum_5^2 + zsum_5^2)^{1/2} \\ &+(xsum_6^2 + ysum_6^2 + zsum_6^2)^{1/2}\end{aligned}}\right]}$$

**Where,**

| | |
|---|---|
| Ti To | Inside and outside air temperature. |
| Lux condition | This is the outside available lux condition (Statistical value) |
| Sky | This is the amount of sky one can see in the different directions of the site. |
| $Vel_{wind}$ | Wind velocity in different directions.(Statistical value) |
| I | Incident radiation.(Calculated) |

for any surface p

$$xsum_p = (y_{P1}z_{P2}-z_{P1}y_{P2}) + (y_{P2}z_{P3}-z_{P2}y_{P3}) + (y_{P3}z_{P4}-z_{P3}y_{P4}) + (y_{P4}z_{P1}-z_{P4}y_{P1})$$
$$ysum_p = (x_{P1}z_{P2}-z_{P1}x_{P2}) + (x_{P2}z_{P3}-z_{P2}x_{P3}) + (x_{P3}z_{P4}-z_{P3}x_{P4}) + (x_{P4}z_{P1}-z_{P4}x_{P1})$$
$$zsum_p = (y_{P1}x_{P2}-x_{P1}y_{P2}) + (y_{P2}x_{P3}-x_{P2}y_{P3}) + (y_{P3}x_{P4}-x_{P3}y_{P4}) + (y_{P4}x_{P1}-x_{P4}y_{P1})$$

## 4.MULTI OBJECTIVE OPTIMISATION (OBTAINING THE PARETO SET)

For the search of the optimal solutions we used a non dominated sorting procedure using Genetic Algorithm (NSGA, K Deb and M Goyal,1994). We had 6 objectives and 62 variables and the procedure was run for 4000 generations. Some modifications were necessary to adapt this algorithm for our purpose. Restrictions were imposed on the way values of the variables defining the form were chosen so that “crumbled” 3 dimensional shapes weren’t produced. During mutation and crossover, similar restrictions were maintained to prevent in the intrusion of “corrupt” forms which usually led to a total failure of the entire search process.

The GS generates a population of possible design solutions and then assesses its performances against the selected criteria. Finally creates dominated and non-dominated fronts in the population. After generations of evolution, the last set of non-dominated designs represents the high performance solutions. (For details refer to *Evolutionary Computation, Vol.2, No.3, Pages 221-248*)

A comparison between the first random generation of 2000 designs against the 4000$^{th}$ generation of the evolution process is illustrated in figure 2. Instead of six fitness values, a single rating system was devised as follows to allow the comparison.

$$\text{Rating} = \sum \text{minmax}_{\text{parameter}} \times \frac{\text{parameter coeff}}{\text{max parameter coeff}} \times \text{weight}_{\text{parameter}}$$

$\text{minmax}_{\text{parameter}}$ = +1 or -1 depending on whether the parameter is to be maximized or minimized.
parameter coeff = performance of the form for the parameter

It is observed that the non-dominated solutions of the 4000th generation get maximum ratings. Infact the lines signify the general (linearly averaged) trend in the two populations. We observe that the last generation shows a significant improvement in the overall rating of the population. However a study using micro-GA which avoids the inertia of such a large population may be done to enquire whether a quicker convergence is possible in this problem.

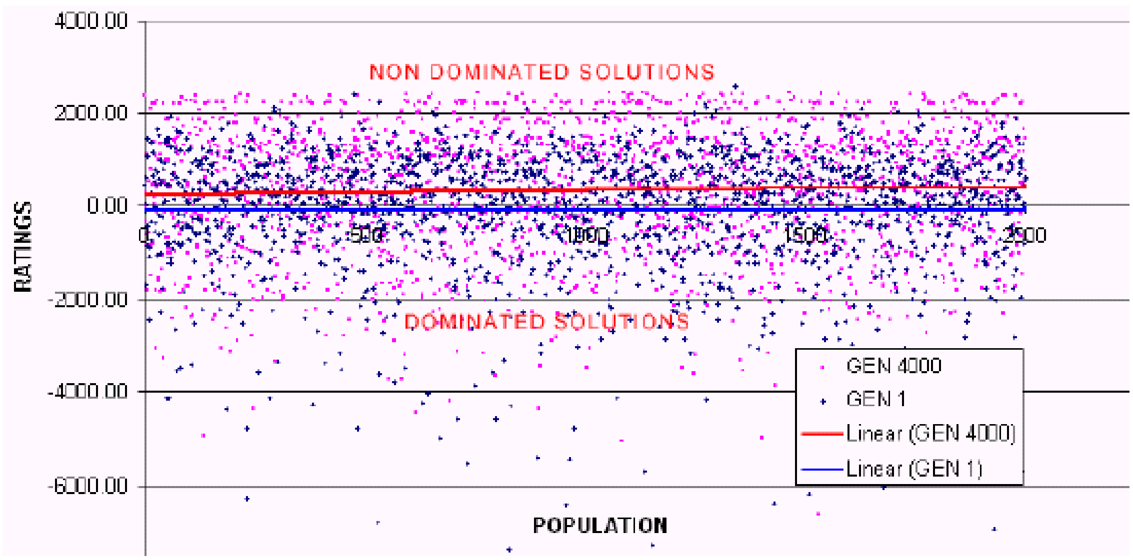
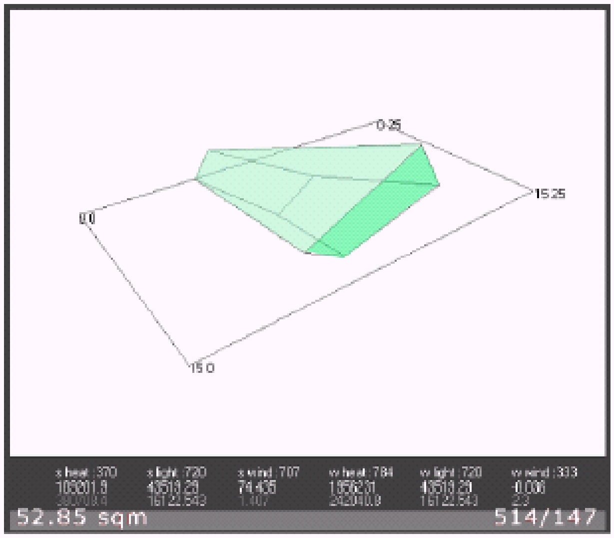


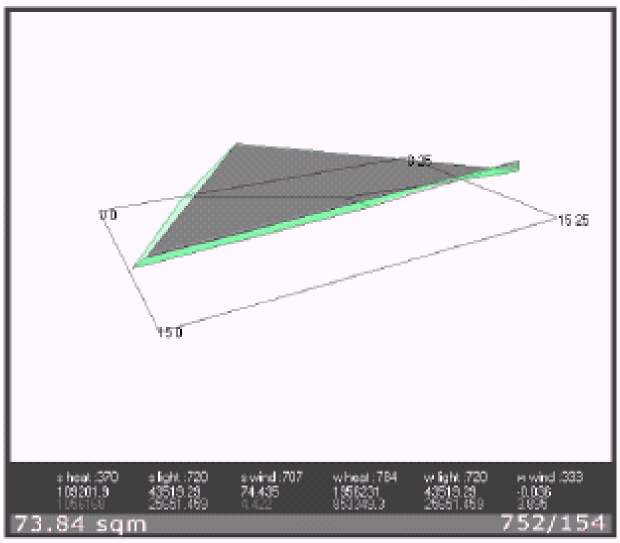

Figure 2 : Comparison between the first generation and 4000$^{th}$ generation in terms of the rating system introduced above (The lines represent the tendency of the two generations).

## RESULTS: SAMPLE SOLUTIONS AND DISCUSSION

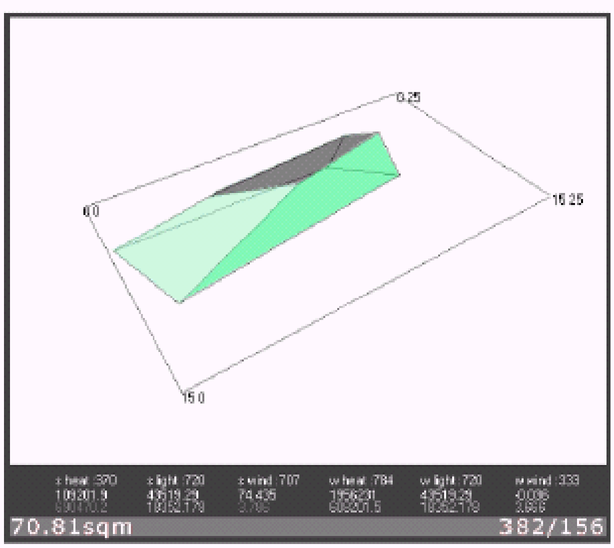
On the basis of the rating system introduced above we have selected a series of non dominated shapes (4000$^{th}$ generation). The variables that were used in the optimisation procedure are listed next to the shapes with their values.



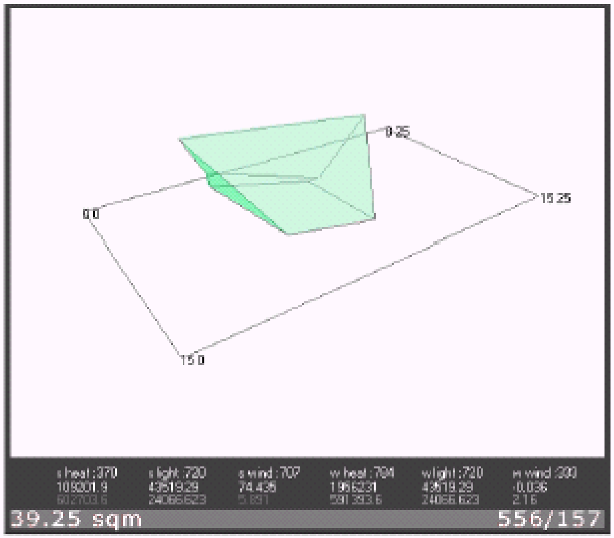

structure 514
v[1], 7.352, 9.734, 0.000
v[2],13.008,10.290, 0.000
v[3],10.695,20.585, 0.000
v[4], 4.610,14.653, 0.000
v[5], 3.940, 6.180, 2.273
v[6],14.298, 6.613, 2.687
v[7],12.593,15.994, 5.023
v[8], 1.669, 8.273, 2.738
u[1] = 6.763 u[2] = 7.093 u[3] = 1.126
u[4] = 5.972 u[5] = 0.873 u[6] = 3.383
a[1] = 0.228 a[2] = 0.538 a[3] = 0.831
a[4] = 0.270 a[5] = 0.509 a[6] = 0.862
r[1] = 0.692 r[2] = 0.737 r[3] = 0.746
r[4] = 0.663 r[5] = 0.709 r[6] = 0.742
w[0] = 0.742,0.829,0.040,0.750
w[1] = 0.648,0.576,0.043,0.720
w[2] = 0.631,0.048,0.830,0.830
w[3] = 0.647,0.537,0.040,0.805
w[4] = 0.646,0.049,0.707,0.828
380708.406, 16122.543, 1.407,
242040.766, 16122.543, 2.300.




structure 752
v[1], 0.216, 5.465, 0.000
v[2], 8.784, 0.214, 0.000
v[3], 7.849,15.807, 0.000
v[4], 5.511,15.127, 0.000
v[5], 6.950, 7.006, 5.320
v[6],11.741, 0.476, 1.947
v[7],12.475,23.617, 3.337
v[8],13.074,23.006, 2.932
u[1] = 5.578 u[2] = 6.816 u[3] = 1.916
u[4] = 1.477 u[5] = 1.087 u[6] = 5.362
a[1] = 0.156 a[2] = 0.549 a[3] = 0.831
a[4] = 0.717 a[5] = 0.521 a[6] = 0.382
r[1] = 0.725 r[2] = 0.739 r[3] = 0.748
r[4] = 0.740 r[5] = 0.741 r[6] = 0.729
w[0] = 0.729,0.830,0.040,0.618
w[1] = 0.650,0.632,0.041,0.752
w[2] = 0.638,0.120,0.830,0.827
w[3] = 0.650,0.665,0.041,0.704
w[4] = 0.611,0.055,0.725,0.781
1056167.625, 25651.459, 4.422,
853349.313, 25651.459, 3.895




structure 382
v[1], 4.620, 0.264, 0.000
v[2],10.135, 1.882, 0.000
v[3], 8.124,18.529, 0.000
v[4], 4.889,14.957, 0.000
v[5], 6.650, 5.810, 3.097
v[6], 9.997, 9.452, 4.761
v[7], 9.439,15.013, 5.461
v[8], 7.832,13.878, 4.759
u[1] = 6.151 u[2] = 7.324 u[3] = 1.114
u[4] = 1.213 u[5] = 0.866 u[6] = 3.192
a[1] = 0.386 a[2] = 0.544 a[3] = 0.152
a[4] = 0.598 a[5] = 0.809 a[6] = 0.372
r[1] = 0.719 r[2] = 0.731 r[3] = 0.746
r[4] = 0.748 r[5] = 0.712 r[6] = 0.315
w[0] = 0.315,0.830,0.040,0.734
w[1] = 0.649,0.429,0.041,0.679
w[2] = 0.607,0.054,0.826,0.826
w[3] = 0.650,0.144,0.044,0.774
w[4] = 0.575,0.062,0.774,0.789
690470.188, 18352.178, 3.786, 608201.500,
18352.178, 3.666

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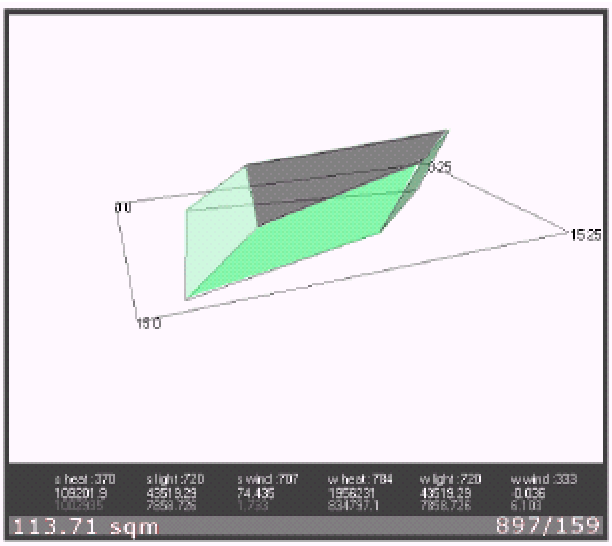
structure 556
v[1], 1.537, 7.863, 0.000
v[2], 9.601, 8.852, 0.000
v[3],11.142,14.172, 0.000
v[4], 4.673,13.789, 0.000
v[5], 4.218, 6.654, 2.490
v[6], 4.832, 4.945, 5.380
v[7], 7.867,15.652, 5.480
v[8], 5.552,14.015, 0.569
u[1] = 6.169 u[2] = 7.434 u[3] = 1.468
u[4] = 0.984 u[5] = 0.954 u[6] = 2.975
a[1] = 0.737 a[2] = 0.551 a[3] = 0.776
a[4] = 0.703 a[5] = 0.866 a[6] = 0.672
r[1] = 0.728 r[2] = 0.738 r[3] = 0.724
r[4] = 0.726 r[5] = 0.708 r[6] = 0.169
w[0] = 0.169,0.830,0.040,0.749
w[1] = 0.649,0.739,0.041,0.682
w[2] = 0.633,0.046,0.827,0.828
w[3] = 0.649,0.273,0.041,0.739
w[4] = 0.611,0.073,0.303,0.775
602703.625, 24066.623, 5.891, 591393.625,
24066.623, 2.160
```

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structure 897
v[1], 3.023, 4.341, 0.000
v[2],14.000, 2.326, 0.000
v[3],10.691,14.465, 0.000
v[4], 5.338,20.549, 0.000
v[5], 1.874, 8.757, 2.247
v[6],11.584, 6.671, 2.085
v[7], 7.524,19.264, 3.147
v[8], 3.063,24.502, 3.585
u[1] = 6.678 u[2] = 7.324 u[3] = 1.114
u[4] = 1.213 u[5] = 0.866 u[6] = 3.392
a[1] = 0.917 a[2] = 0.335 a[3] = 0.206
a[4] = 0.584 a[5] = 0.605 a[6] = 0.678
r[1] = 0.742 r[2] = 0.719 r[3] = 0.739
r[4] = 0.736 r[5] = 0.743 r[6] = 0.750
w[0] = 0.750,0.830,0.040,0.704
w[1] = 0.649,0.629,0.043,0.801
w[2] = 0.606,0.044,0.829,0.822
w[3] = 0.650,0.525,0.042,0.822
w[4] = 0.236,0.064,0.533,0.780
1002934.875, 7858.726, 1.733,
834797.125, 7858.726, 6.103
```
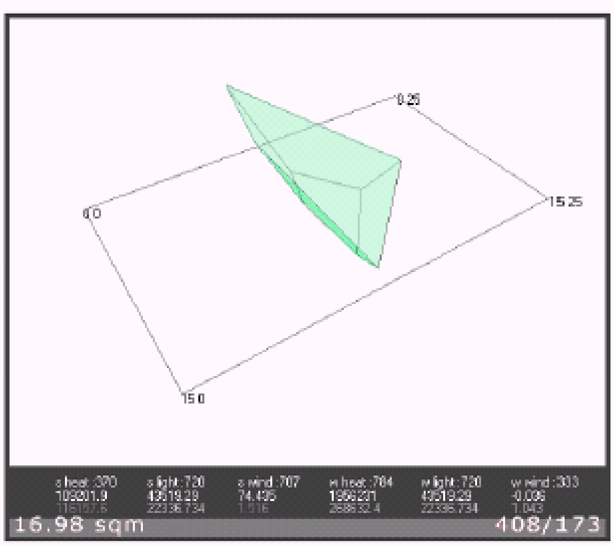
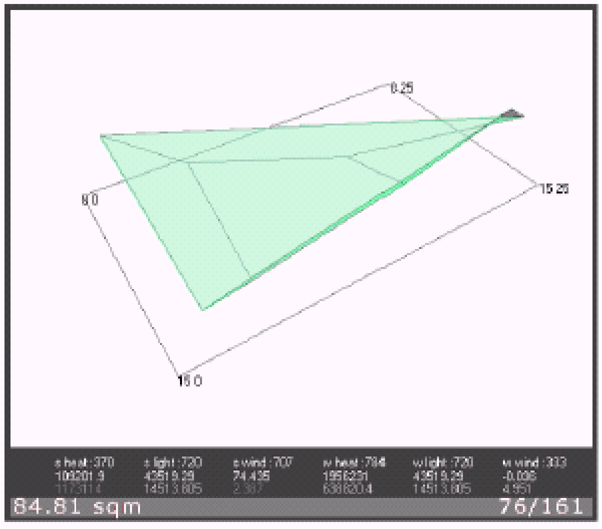
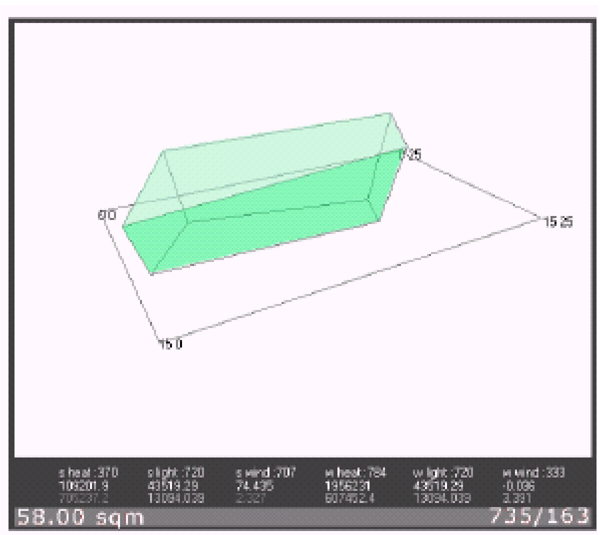



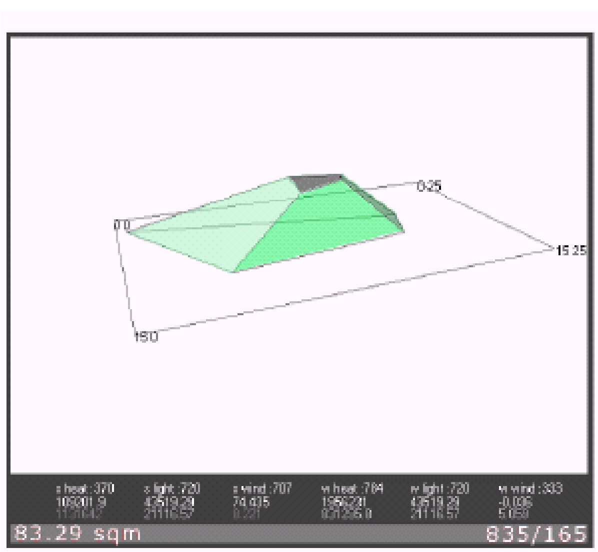

```
structure 408
v[1], 6.979,11.726, 0.000
v[2],12.305,11.918, 0.000
v[3], 7.782,15.595, 0.000
v[4], 3.693,12.731, 0.000
v[5], 5.103, 9.680, 4.352
v[6],14.721,11.321, 1.503
v[7], 9.692,16.837, 3.073
v[8], 0.428,10.265, 5.753
u[1] = 6.016 u[2] = 6.243 u[3] = 1.181
u[4] = 4.891 u[5] = 0.852 u[6] = 2.849
a[1] = 0.696 a[2] = 0.552 a[3] = 0.784
a[4] = 0.624 a[5] = 0.903 a[6] = 0.712
r[1] = 0.749 r[2] = 0.738 r[3] = 0.741
r[4] = 0.701 r[5] = 0.739 r[6] = 0.709
w[0] = 0.709,0.829,0.040,0.722
w[1] = 0.649,0.578,0.040,0.720
w[2] = 0.638,0.100,0.826,0.820
w[3] = 0.649,0.520,0.041,0.817
w[4] = 0.634,0.042,0.800,0.772
116157.602, 22336.734, 1.516, 268632.406,
22336.734, 1.043
```



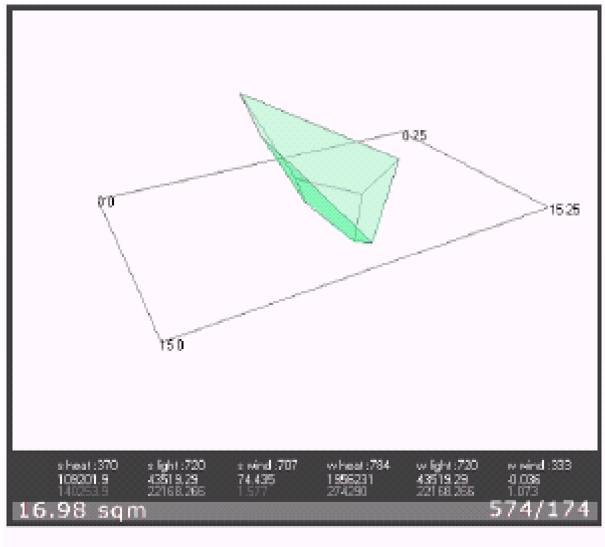

structure 76
v[1], 0.530, 6.962, 0.000
v[2],11.873, 5.665, 0.000
v[3],10.126,17.840, 0.000
v[4], 5.782,16.437, 0.000
v[5], 1.321, 2.071, 4.774
v[6],14.435, 1.966, 3.387
v[7],12.438,23.109, 5.119
v[8],13.299,23.321, 5.044
u[1] = 6.763 u[2] = 7.093 u[3] = 1.126
u[4] = 5.972 u[5] = 0.884 u[6] = 7.255
a[1] = 0.803 a[2] = 0.687 a[3] = 0.284
a[4] = 0.786 a[5] = 0.500 a[6] = 0.723
r[1] = 0.714 r[2] = 0.727 r[3] = 0.744
r[4] = 0.721 r[5] = 0.749 r[6] = 0.717
w[0] = 0.717,0.830,0.040,0.719
w[1] = 0.650,0.434,0.043,0.692
w[2] = 0.235,0.047,0.829,0.821
w[3] = 0.650,0.547,0.044,0.813
w[4] = 0.630,0.064,0.792,0.807
1173113.750, 14513.805, 2.387,
638820.438, 14513.805, 4.951



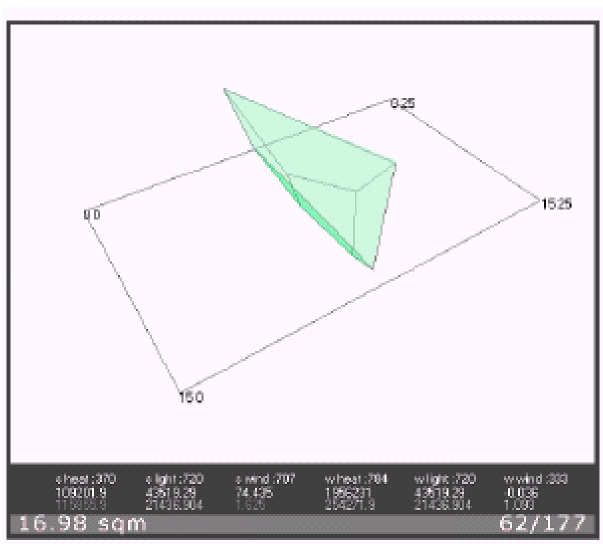

structure 735
v[1], 4.368, 4.618, 0.000
v[2], 9.361, 1.067, 0.000
v[3],10.218,15.477, 0.000
v[4], 7.093,16.687, 0.000
v[5], 3.619, 3.939, 4.795
v[6], 9.538, 0.107, 3.299
v[7],10.647,16.686, 5.039
v[8], 6.751,18.439, 5.934
u[1] = 6.907 u[2] = 6.573 u[3] = 1.105
u[4] = 4.924 u[5] = 0.878 u[6] = 5.826
a[1] = 0.886 a[2] = 0.580 a[3] = 0.141
a[4] = 0.229 a[5] = 0.571 a[6] = 0.144
r[1] = 0.740 r[2] = 0.736 r[3] = 0.747
r[4] = 0.708 r[5] = 0.707 r[6] = 0.152
w[0] = 0.152,0.827,0.040,0.709
w[1] = 0.648,0.606,0.042,0.676
w[2] = 0.180,0.088,0.828,0.828
w[3] = 0.650,0.535,0.046,0.708
w[4] = 0.635,0.044,0.813,0.780
705237.188, 13094.039, 2.327, 607452.438,
13094.039, 3.391



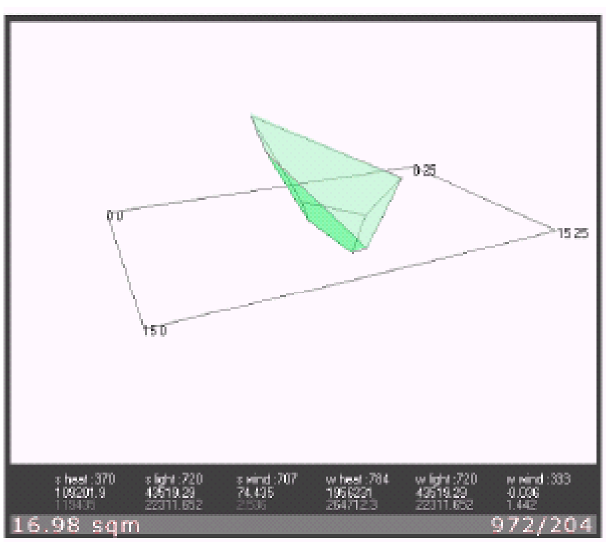

structure 835
v[1], 2.351, 0.655, 0.000
v[2],10.641, 5.687, 0.000
v[3], 9.300,17.759, 0.000
v[4], 6.309,18.999, 0.000
v[5], 6.523,10.645, 3.925
v[6], 8.290,10.787, 3.435
v[7], 7.816,13.800, 3.705
v[8], 7.190,13.840, 3.882
u[1] = 6.340 u[2] = 7.332 u[3] = 1.079
u[4] = 6.643 u[5] = 0.893 u[6] = 4.005
a[1] = 0.106 a[2] = 0.539 a[3] = 0.232
a[4] = 0.934 a[5] = 0.735 a[6] = 0.886
r[1] = 0.737 r[2] = 0.738 r[3] = 0.738
r[4] = 0.721 r[5] = 0.749 r[6] = 0.726
w[0] = 0.726,0.829,0.040,0.643
w[1] = 0.650,0.737,0.041,0.770
w[2] = 0.621,0.099,0.829,0.829
w[3] = 0.650,0.520,0.042,0.808
w[4] = 0.597,0.056,0.522,0.803
1131642.000, 21116.570, 8.221,
831295.750, 21116.570, 5.059




structure 574
v[1], 6.979,11.726, 0.000
v[2],12.305,11.918, 0.000
v[3], 7.782,15.595, 0.000
v[4], 3.693,12.731, 0.000
v[5], 5.103, 9.680, 4.352
v[6],14.721,11.321, 1.503
v[7], 9.692,16.837, 3.073
v[8], 0.428,10.265, 5.753
u[1] = 6.016 u[2] = 6.249 u[3] = 2.344
u[4] = 4.866 u[5] = 0.873 u[6] = 2.213
a[1] = 0.347 a[2] = 0.599 a[3] = 0.200
a[4] = 0.299 a[5] = 0.540 a[6] = 0.852
r[1] = 0.749 r[2] = 0.663 r[3] = 0.747
r[4] = 0.740 r[5] = 0.686 r[6] = 0.269
w[0] = 0.269,0.828,0.040,0.621
w[1] = 0.640,0.578,0.041,0.731
w[2] = 0.626,0.141,0.827,0.830
w[3] = 0.649,0.599,0.044,0.751
w[4] = 0.633,0.045,0.717,0.827
140253.859, 22168.266, 1.577, 274290.031,
22168.266, 1.073




structure 62
v[1], 6.979,11.726, 0.000
v[2],12.305,11.918, 0.000
v[3], 7.782,15.595, 0.000
v[4], 3.693,12.731, 0.000
v[5], 5.103, 9.680, 4.352
v[6],14.721,11.321, 1.503
v[7], 9.692,16.837, 3.073
v[8], 0.428,10.265, 5.753
u[1] = 6.011 u[2] = 6.306 u[3] = 1.195
u[4] = 4.805 u[5] = 0.856 u[6] = 7.304
a[1] = 0.707 a[2] = 0.350 a[3] = 0.277
a[4] = 0.442 a[5] = 0.529 a[6] = 0.453
r[1] = 0.740 r[2] = 0.731 r[3] = 0.722
r[4] = 0.707 r[5] = 0.706 r[6] = 0.672
w[0] = 0.672,0.829,0.040,0.714
w[1] = 0.650,0.739,0.040,0.730
w[2] = 0.598,0.046,0.828,0.825
w[3] = 0.650,0.273,0.041,0.812
w[4] = 0.597,0.047,0.697,0.821
115855.938, 21436.904, 1.625, 254271.906,
21436.904, 1.093



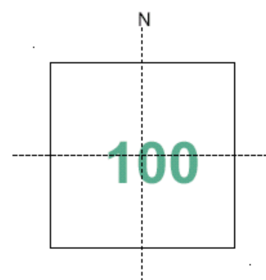

structure 972
v[1], 6.979,11.726, 0.000
v[2],12.305,11.918, 0.000
v[3], 7.782,15.595, 0.000
v[4], 3.693,12.731, 0.000
v[5], 5.103, 9.680, 4.352
v[6],14.721,11.321, 1.503
v[7], 9.692,16.837, 3.073
v[8], 0.428,10.265, 5.753
u[1] = 6.016 u[2] = 6.243 u[3] = 1.181
u[4] = 4.891 u[5] = 0.852 u[6] = 2.849
a[1] = 0.696 a[2] = 0.552 a[3] = 0.784
a[4] = 0.624 a[5] = 0.903 a[6] = 0.712
r[1] = 0.749 r[2] = 0.738 r[3] = 0.741
r[4] = 0.740 r[5] = 0.688 r[6] = 0.243
w[0] = 0.243,0.830,0.040,0.684
w[1] = 0.650,0.394,0.040,0.767
w[2] = 0.608,0.042,0.826,0.813
w[3] = 0.649,0.333,0.041,0.830
w[4] = 0.615,0.076,0.314,0.825
119434.992, 22311.652, 2.536, 264712.344,
22311.652, 1.442

## COMPARATIVE ANALYSIS AGAINST CONVENTIONAL FORMS

The following is a comparative analysis of conventionally used forms as against the forms suggested by the optimisation engine. Notably, the optimised form reduces heat gain (major comfort factor in Kolkata) by around 30% than the conventional form by reorienting its walls and without compromising with the air change rates. The following are the results.

note:1.The ratings are relative to the generic square shape. 2. All three-dimensional shapes compared have equal volumes. 3.The same equations that was used in the optimisation procedure was reused to evaluate the parameters listed below

### GENERIC TYPE 1 (SQUARE PLAN)




Total heat gain summer (without fenestration)--> 650722.0J

Total heat gain summer (with fenestration)--> 790138.25J

Total heat gain winter (without fenestration)--> 1122430.0J

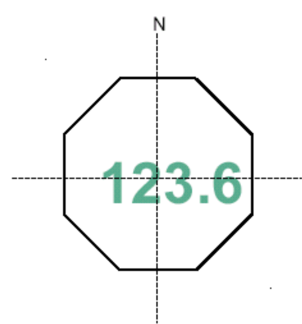
Total heat gain winter (with fenestration)-->1370586.75J

Air change rate summer--> 2.9

Air change rate winter--> 1.45

Average daylight factor-->6.80

### GENERIC TYPE 2 (OCTAGON)



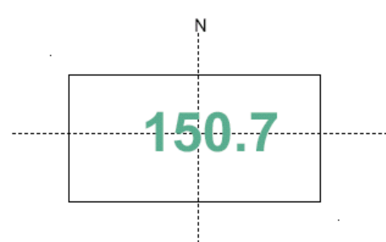

Total heat gain summer (without fenestration)-->526627.58J

Total heat gain summer (with fenestration)-->629851.00J

Total heat gain winter (without fenestration)-->869491J

Total heat gain winter (with fenestration)-->1057847.15J

### CONVENTIONAL (RECTANGULAR WITH N - S FACADE INCREASED)




Total heat gain summer (without fenestration)--> 431968.43J

Total heat gain summer (with fenestration)--> 520241.75J

Total heat gain winter (with fenestration)--> 1349999.37J

Air change rate summer--> 2.3

Air change rate winter--> 1.11

Average daylight factor-->6.81

### MODIFIED NON DOMINATED SYNTAX (INCLINED WALLS STRAIGHTENED)

Total heat gain summer (without fenestration)--> 323849.31J

Total heat gain summer (with fenestration)--> 372335.15J

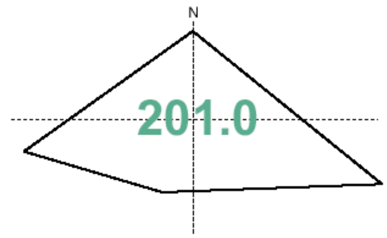
Total heat gain winter (without fenestration)--> 782399.93J

Total heat gain winter (with fenestration)--> 672194.06J

air change rate summer--> 4.6

air change rate winter--> 1.2

average daylight factor-->5.71




### NON DOMINATED SYNTAX (REFER RESULTS)

Total heat gain summer(without fenestration)-> 310776.81J

Total heat gain summer (with fenestration)--> 339054.062J

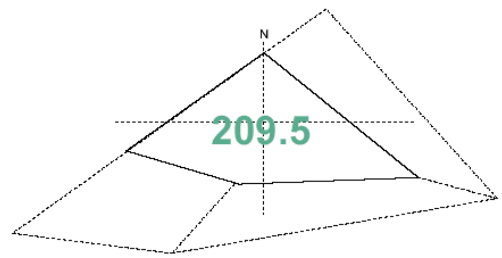
Total heat gain winter (without fenestration)--> 549525.06J

Total heat gain winter (with fenestration)--> 672194.06J

air change rate summer--> 4.6

air change rate winter--> 1.12

average daylight factor-->4.94




## DISCUSSION ON THE RESULTS OF THE GENERATIVE SYSTEM

1.The fact that there isn't any unique solution but several high performance solutions is well suited to the architectural context as the designer can further develop one or more of these by considering other criteria, which are not included in the search process. There are two ways to develop further on these primitive shapes,

(a) Human

The best human strategy would be to work in an evaluative environment where the consequences of any intuitive decision are constantly assessed. The user thereby knows the exact effects of the deviation he makes. There will be soft and hard parameters. Soft parameters can be relaxed and any human intervention would not drastically reduce the form's performance while any deviations for the hard parameters would destroy the optimum balance immediately. The intuitive designer thus has to work within a few limitations

(b) Machine

Further computational methods can be employed to work and interact with these shapes and to achieve certain defined goals. (fig 3)

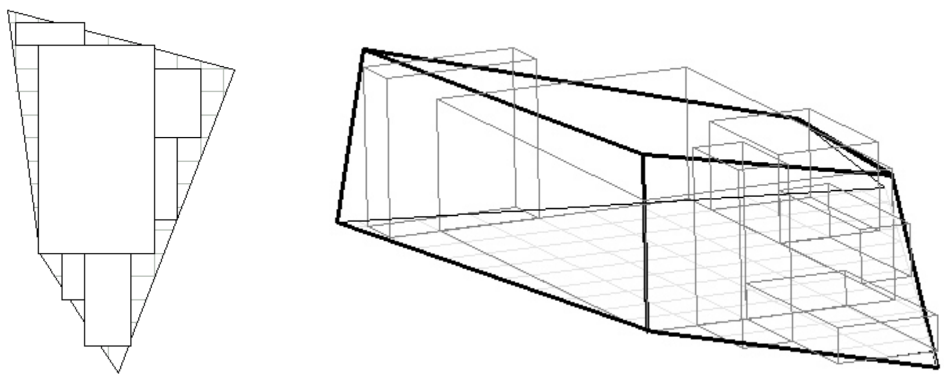


figure 3: The optimum shapes can be treated as an envelop and deviations can be assessed by an evaluation software.

2.One may not really strictly stick to these shapes but once you have an optimised benchmark, you can objectively calculate how much you are deviating. An appraisal of the economic and energy cost of deviation would definitely help one justify such decisions in objective terms.

3.All the forms are characterised by their skewness. It was of course expected beforehand when the constraint of having only vertical walls was removed. The sun and the wind vectors interplay at angles to provide this skewness. The obvious factors that consequently follow are the questions on ergonomics and psychology. It should be reminded that we have just optimised for climatic parameters only, the reason being that a complete comprehensive architectural form designer/optimizer shall take several doctoral researches to complete. The inclusion of ergonomics and psychology is just a question extending the scope of the optimisation engine and appending additional objective functions.

Looking at it from another angle if there aren't any constructional hazards (thanks to modern technology) this skewness can actually become a style! These primitive shapes can be connected by noninterfering connectors to form a new kind of experimental architecture.

## CONCLUSION AND FURTHER SCOPE OF WORK

Generative systems like the one demonstrated in this paper may not replace the black box of human creativity but definitely they provide a fast and efficient means for local searches using given criteria (for which specific knowledge bases are available). Thus the objective of GS is not to produce definite and absolute optimums but to explore and suggest potential strategies at the early stages of design to tackle the criteria the user chooses for exploration.

Further work

- The simulations models used in this paper are simple and based on steady state equations. Further work needs to be done to integrate more accurate transient state models.
- Design of a tailored GA for the purpose. Some research needs to be done to find whether there is a possible global optimum and how to achieve it quickly.

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