Multi Objective Genetic Algorithm

The environment

Multi objective Genetic Algorithm differs from the one described on http://wiki.uelceca.net/msc0809/show/GA+-+Solar+Gain in the implementation of the environment and the fitness function.
With regard to the representation of the environment, it can be structured by encoding computational schemes whereby simulating different performative aspects. This evaluation will then feed the so called "fitness function" for the assignment of a value for each individual in population .The computational schemes that I have been able to develop are mainly based on vector fields for the simulation of sun and wind, the others, such as spatial organization, rely on geometric evaluations. Sun analysis and wind analysis are indeed cases where intensive measurement is performed. In this case the vector evaluation is linked to the empirical laws given by the British Standard Normative ENV 1991-2-4 whereby the geometric configuration is tested.
The representation of the environment can be described as follows :

- **gravity**, which is simulated as a condition of equilibrium checking the position of the volumetric centroid
- **sun**, whose action is instrumented in order to maximize solar gain on the 21st of December
- **wind**, whose action is instrumented for evolving shapes that minimize its impact on them
- **geometric limits**, which is an index of feasibility of their structure
- **spatial organization**, which influences both the external morphology and the internal layout.

Taking into account the organization of space is mainly expressed by three parameters whose optimization tend to maximise the allocation of volume at higher position, minimize the footprint, minimise the size of the external surface (Facade area) and maximise the total area of floors.
It is worth mentioning that when having more than one fitness criteria the development of an efficient and rigorous fitness function is crucial for the effectiveness of the procedure. In this experiment 7 parameters with different dimension need to be weighted for making one fitness value for each individual. For not losing the contribution of any parameter especially when having some of them whose value counteracts others value, they first need to be normalized. After doing this, the designer can assign a set of weights in order to drive the evolution according to the importance that each of those has in the design process.
The Multi Objective GA that I implemented in based on the "weighted sum approach" where there is as set of weights to assign to the fitness parameter.
There are a series of newly developed algorithm which are based on a different system to tackle with many fitness parameters at time. Non dominance of the solutions and Pateto Optimality are the two main concepts on which these procedure (such as *SPEA II, NSGA II, DMOEA* etc.) rely. However, the implementation of such methods goes beyond the scope of this research and we leave it to future steps.

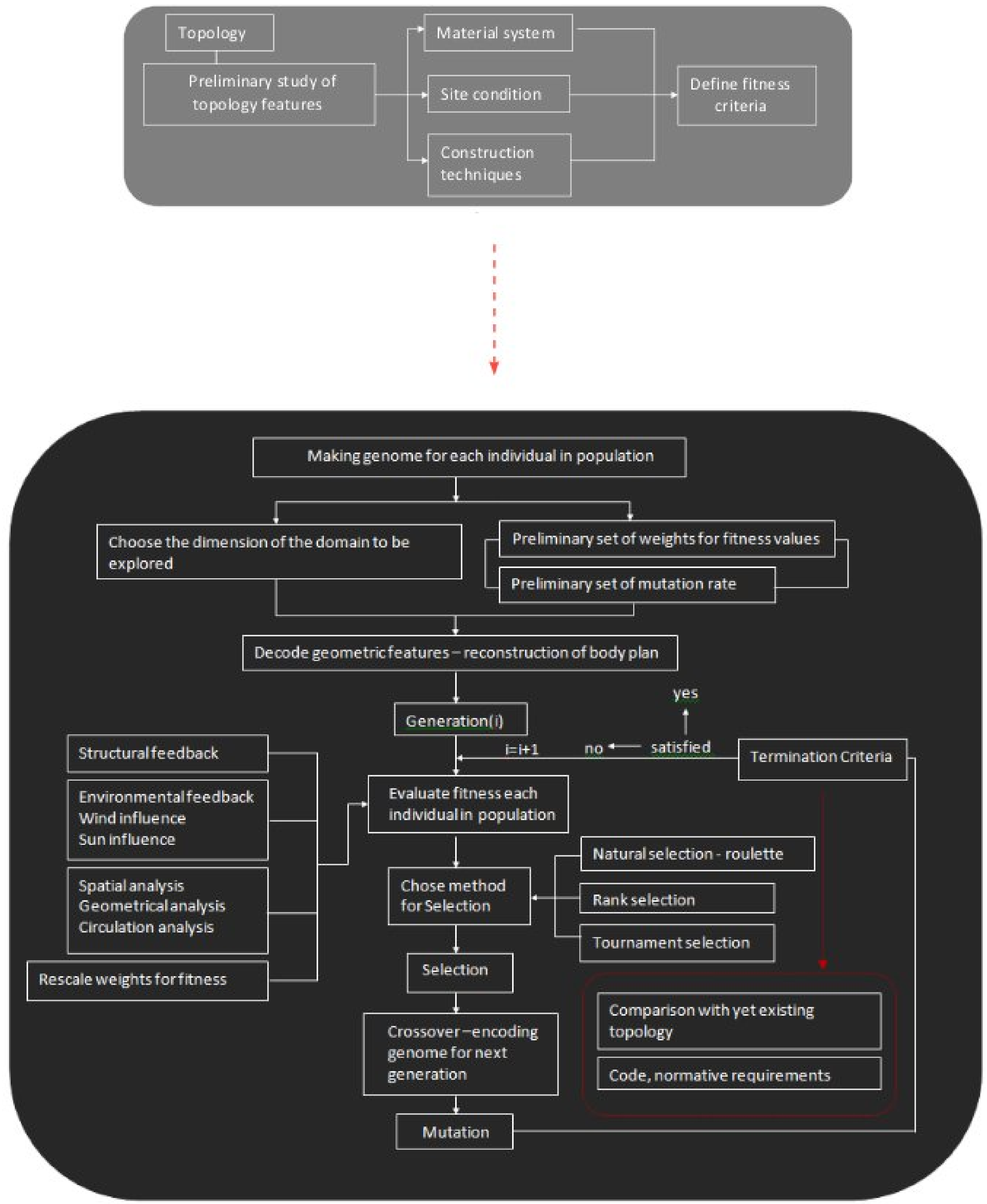


Fig 1 Multi Objective GA flow chart

Encoding the body plan

The topology that we are interested to explore, shown in *fig3*, can be described as Nurbs surface that encloses a volume.
Once again our design variables are the position of the points whereby the geometry is described. In this way the three dimensional dominium of possible positions of these points is explored in order to obtain a set of solution that are consistent with the design criteria.
The way for representing this geometry has been done by assigning the positions of points through which spline curves are drawn. The coordinates of these points, that represent the design variables, are encoded in string of 0&1 *(fig2)*. In general we can have any number of points for describing the surface, in the example shown in *fig3* we have 8 points per section which are interpolated with Nurbs curves creating 6 sections. A lateral surface is then created by lofting these sections.
In order to created a cap that respect the morphology of the individual I implemented a procedure for closing any sort of periodic surface with G2 continuity.
This is done by dividing the surface domain in two parts and taking the isocurves for each of these sides. It is possible then to blend these curves in order to build the structure for the cap. A cap is indeed created by lofting these last built set of curves (*fig1*).
The procedure can be also used to blend surfaces of any kind.

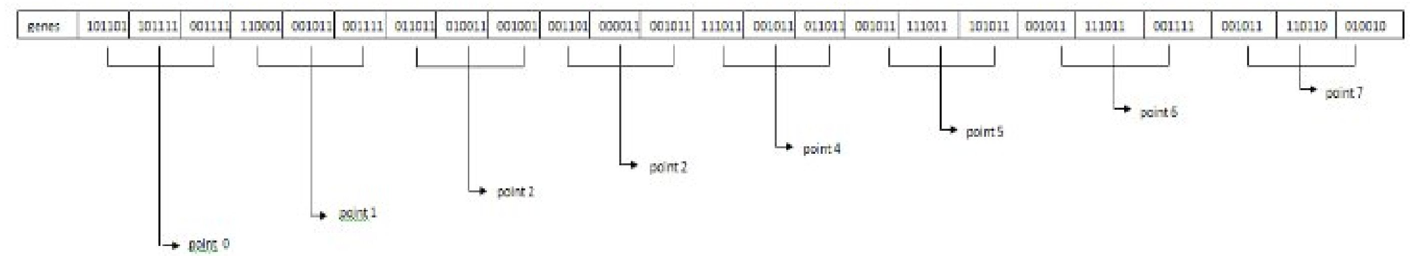


Fig 2 decoding the genes

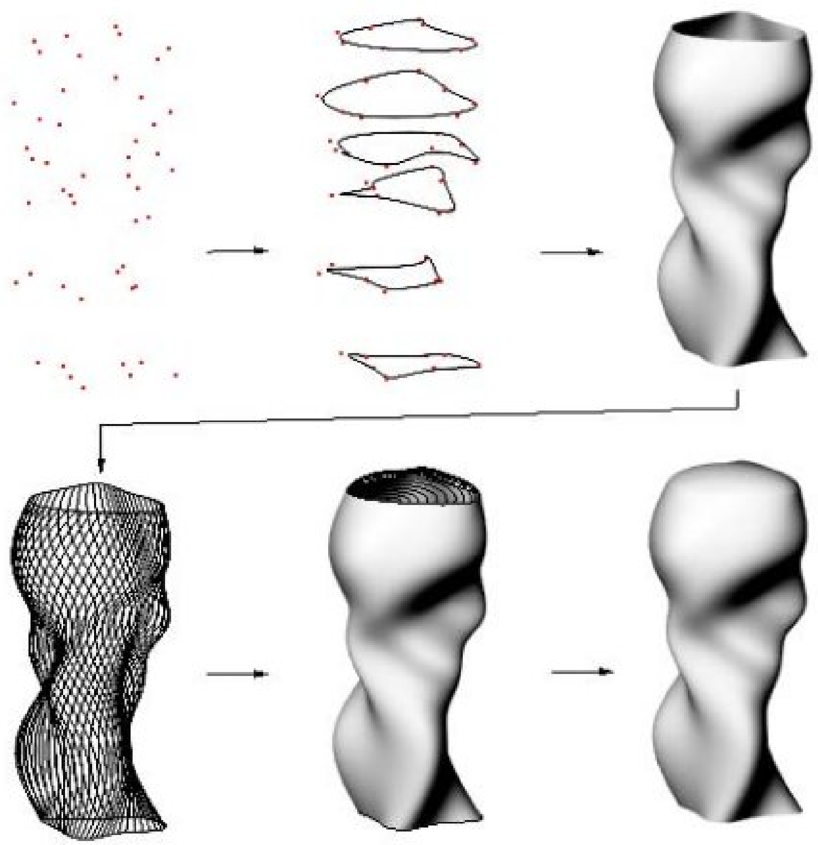


Fig 1 building the body plan

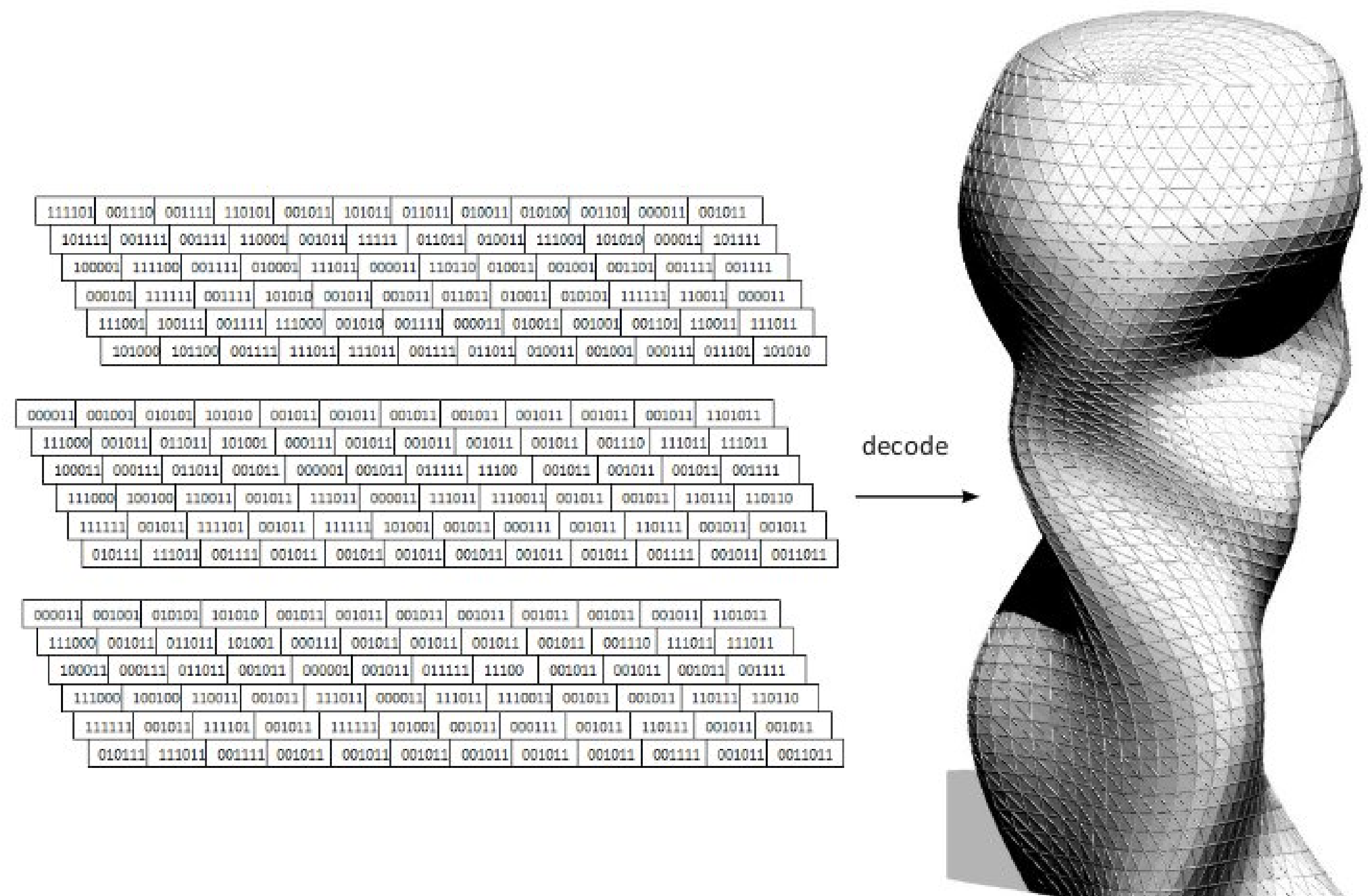


Fig 3 the whole genome

Solar gain

Great advances have been recently done in this field whose results can be summarized in few key elements. Creating large areas of south-facing glazing walls and heavily insulated north facing ones, allows to maximise solar energy gain and daylight while minimizing thermal losses. In this way the southern tract can house space that have to be used for a longer period as office or residential which would also have open view through wide areas of glazing [8].
By keeping heating or cooling energy in floor slabs that have a high thermal capacity, it is possible to release this energy at a later time for reducing temperature extreme and , in so doing, achieving a balanced indoor climate [8][2].
As already explained in the essay GA - Solar Gain on http://wiki.uelceca.net/msc0809/show/GA+-+Solar+Gain the chosen day is the 21st of December because we want to maximize solar gain during the winter and in the shortest day.
Fig3 shows the sun path from 9:00 to 15:00 and the north facing wall of one of the individual where the north direction is represented by the y axis in the world coordinate system. In order to keep the algorithm as light as possible I developed a procedure whereby the nurbs surface is replaced by a mesh from which normal vectors to each of its faces are extracted (*fig2*).
For each hour of the day there is a vector that represent the the sun direction at specified latitude and longitude.
By calculating the angle (*fig1 alfa*) that each vector, representing a sun direction, makes with the normal vector to each panel, it is possible to retrieve information regarding the exposure of the individual. Manipulating this information lead to determine the percentage of solar gain and to draw a map that shows the average exposure of the individual during the examined day.

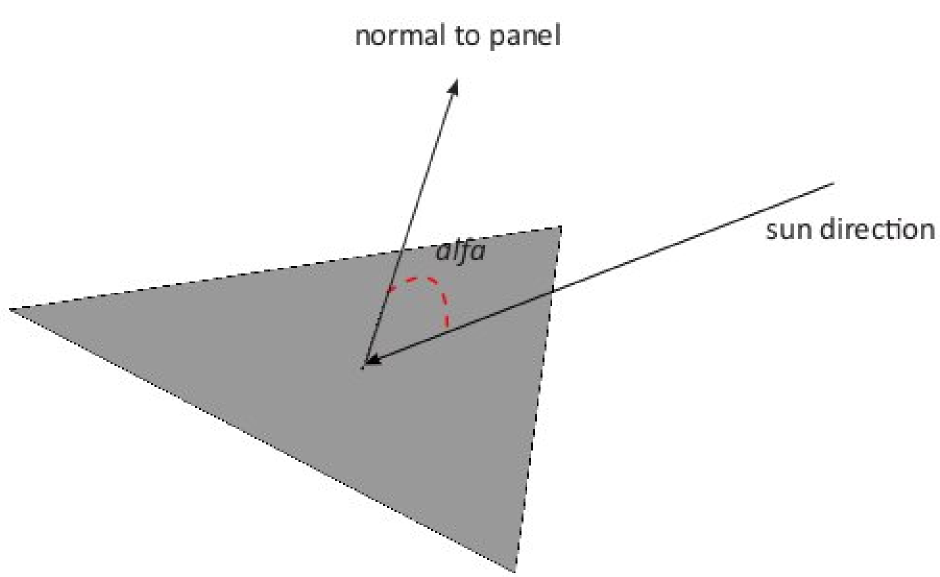


Fig 1 mesh face

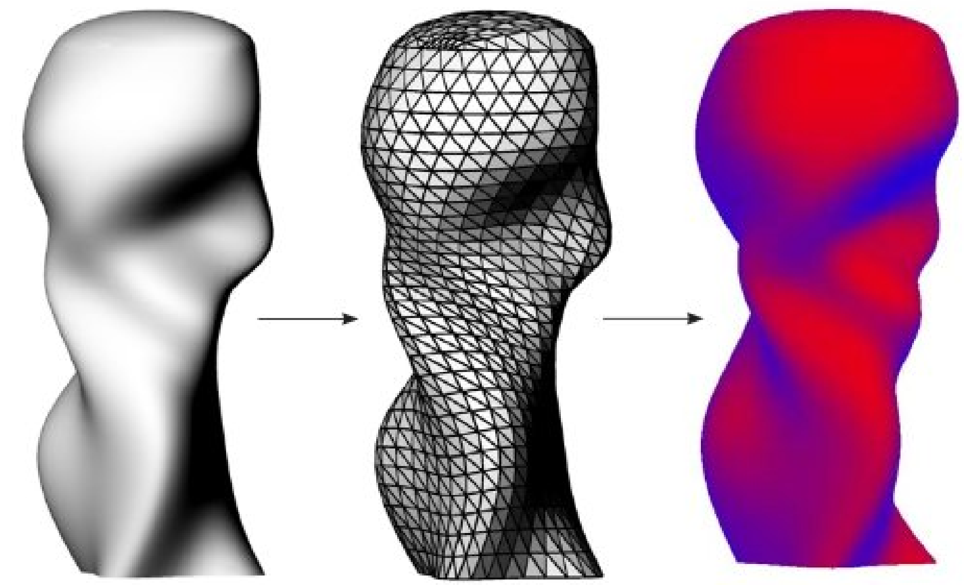


Fig 2 surface mesh map

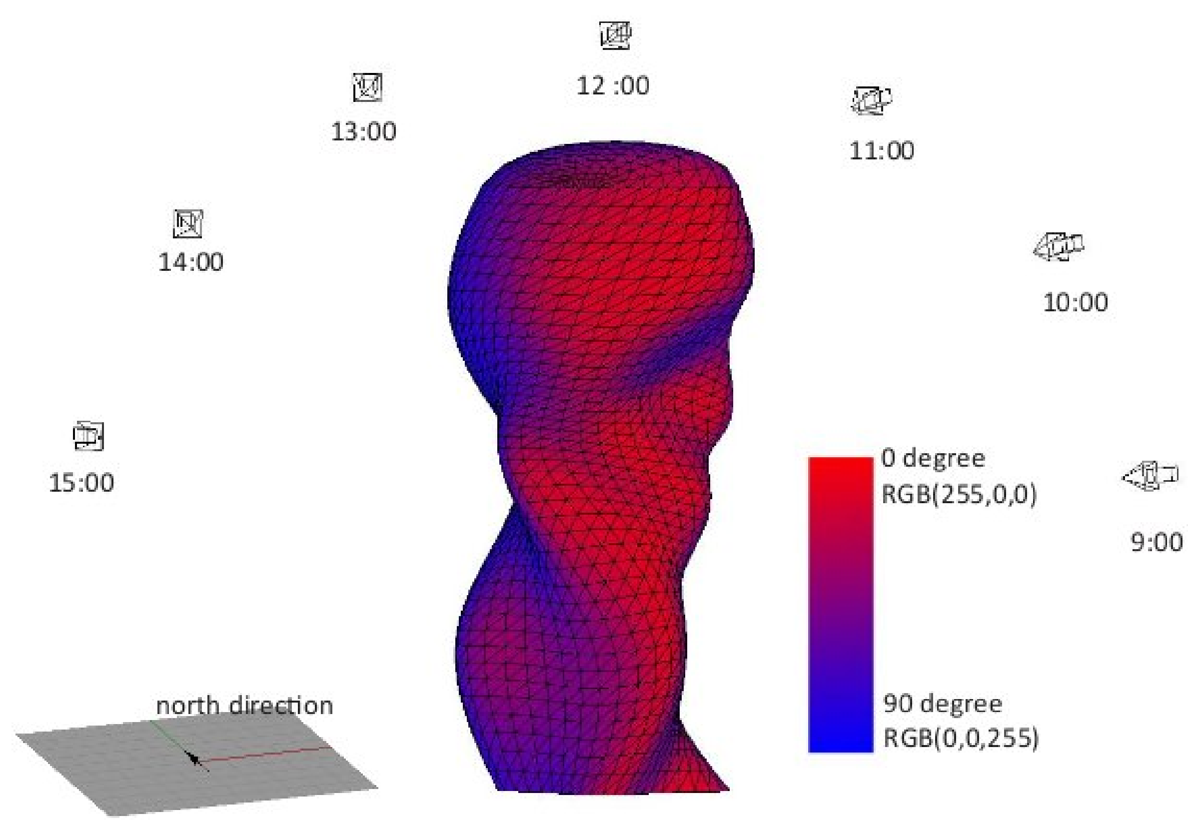


Fig 3 GA flow chart

Wind analysis

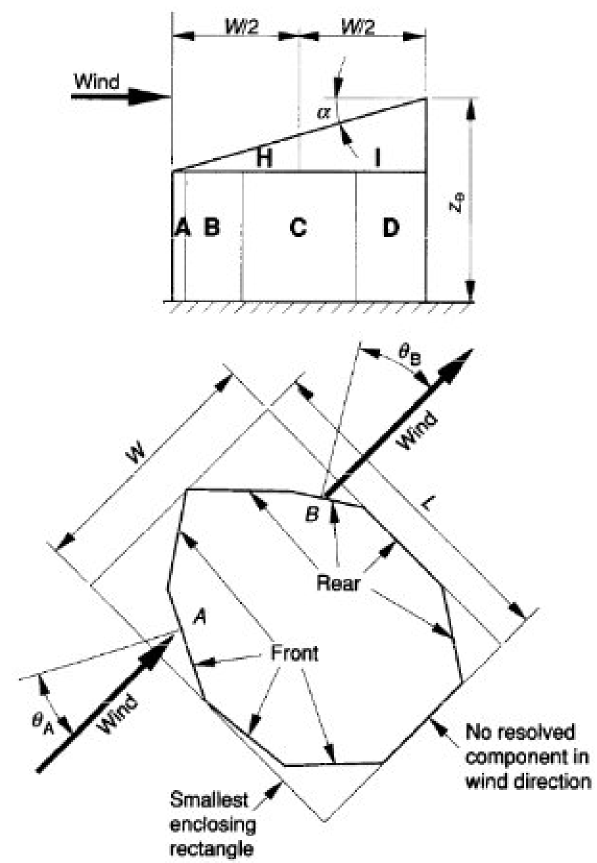
The procedure here presented relies on the British standard normative ENV 1991-2-4 for wind analysis which takes into account, amongst other parameters, the direction of the wind and the orientation of an exposed surface. Although the results that come from this procedure are approximated, compared to the ones that would come from a CFD simulation, they are sufficient for the scope of this research. The reason why this algorithm has been developed is mainly due to computation resource limits. If one wants to analyse each individual, with a software that performs CFD analysis, it will slow down the whole process of an unreasonable amount of time.

The procedure maily consists in two steps :

- the upwind and the downwind size of the building are localised
- the angle between the normal to each panel that form the mesh of the individual and wind is computed
- the normative provide a set of conditions and tables of coefficient that are possible to retrieve we know the two above mentioned information

From these tables is possible to extract the “pressure coefficient” which multiplied by the reference pressure (squared of velocity of the wind*density/2) will give back the pressure caused by the wind on each panel. This information can be then visualised in a map using RGB colours for the vertices of the mesh.

In order to have a fitness value for each individual that describe its behaviour respect to wind, the pressure that acts on each of its face is compared with the value of the reference pressure. The faces whose absolute pressure value is bigger than a certain percentage of the reference pressure are counted. This number is divided over the total number of faces in the mesh for having a normalised value. The reason why is the absolute value to be taken into account is because the wind creates large area of negative pressure when investing a building. The so determined fitness represents, therefore , the percentage of faces whose absolute pressure value is bigger than a specified threshold giving information that regard the efficiency of the individual as a whole.



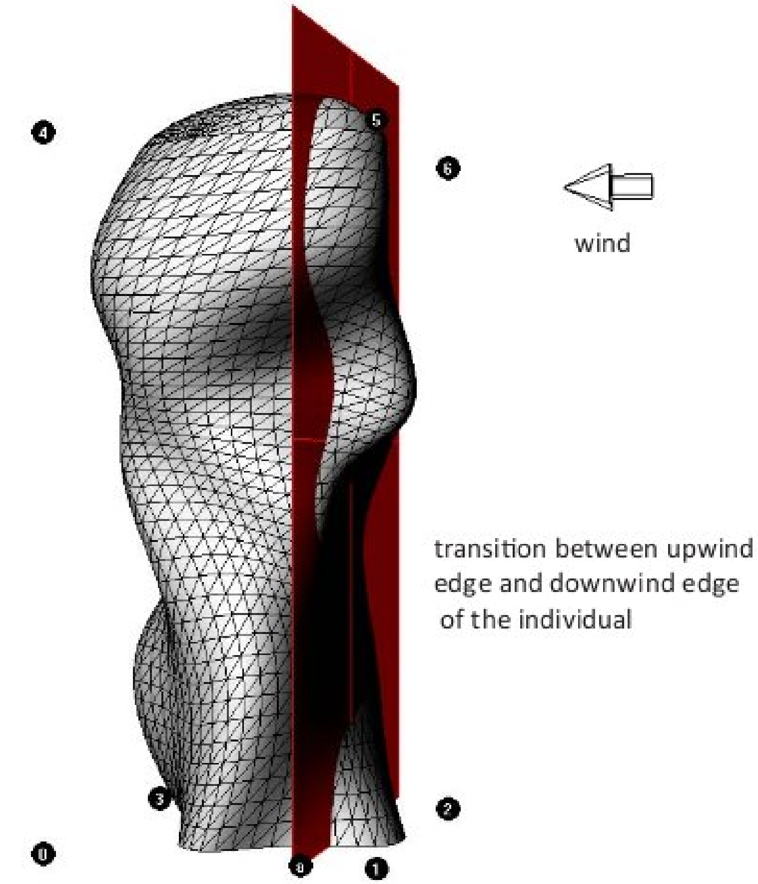


Fig2

using the normative

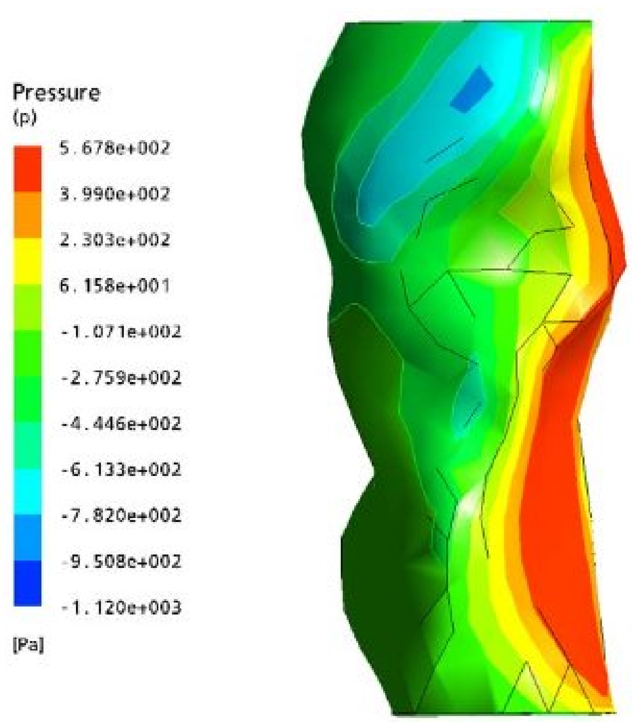


Fig 1

front view, ansys CFD simulation

Fig3

perspective back view

perspective front view

Normalizing the fitness parameters| fitness function

Considering that a genetic algorithm makes a parallel search into the solution domain working with an entire set of solutions at time, we need to avoid the risk of comparing values that are not mathematically comparable. The definition of a fitness function for leading the Genetic Algorithm in a specific direction is crucial. This function performs the evaluation of the individuals giving them a score which is afterwards translated into a probability to be selected.

The second procedure instead, which is the one that I adopt, provide the fitness function with a set of reference values. The fitness parameters of the individuals can be expressed as multiples, fraction or percentage of these.

In order to normalize them, we first need to understand what are the boundaries of the chosen solution domain. If the coordinate of each point is encoded in a string of 0&1 of length 6, it means that its value can vary from 1 to 63 (as already on http://wiki.uelceca.net/msc0809/show/GA+-+Solar+Gain). If they all happen to have the maximum value of 63, they will describe the section shown in *fig2 right*. In addition, considering that the distance between two sections it is controlled by genes, it can vary from 1 to 63 as well. If all the sections are spaced of the maximum value, we can calculate the maximum volume and maximum surface area possible for the size of the chosen solution domain *(fig2 right)*. We should decide carefully the size of the solution domain for each parameter adding constraint to ease the searching and avoid waste of resources. Adding constraints means to understand what is the space of the solution domain where we want to search.

With the same consideration given for the maximum volume, it is possible to retrieve, from the chosen solution domain, all the information that we need for normalizing the fitness parameters:

- min and max area footprint
- min and max lateral surface area (Facade area)
- min and max volume
- min and max height of the volumetric centroid

A part from the fitness related to sun and wind exposure, which for the way are computed, come already normalised, these information are used to normalise all the other fitness parameters. They are :

- *Volume over Footprint*, the ratio between the volume of the individuals and their footprint; to minimise the footprint of the individual
- *Volume over Facade area*, the ratio between the volume of the individuals and their lateral area; to test how efficient is the examined form to enclose a volume
- *Facade to Floors ratio*, the ratio between the total floors area, which is the sum of the area of each floor, and the relative facade area ; it is essentially an index of economy efficiency being facades the most expensive part to build
- *Gravity,* by projecting the volumetric centroid and checking if it falls within the perimeter of the first section; if it falls inside the building will stand otherwise will tend to lean over
- *Height of the Volumetric Centroid,* to maximise the allocation of volume at higher position
- *Min radius of Curvature,* it checks the smallet radius of curvature featured by the surface. It is an index a feasibility, too small radii create problems for connectivity

$$(V/F\_A)min < V/(F\_A) < (V/F\_A)max$$

$$\frac{V}{F_A} - \left(\frac{V}{F_A}\right)min < \left(\frac{V}{F_A}\right)max - (V/F\_A)min$$

$$\text{Fitness norm} = \frac{\left(\frac{V}{F_A}\right) - \left(\frac{V}{F_A}\right)\min}{\left(\frac{V}{F_A}\right)max - \left(\frac{V}{F_A}\right)\min} < 1$$

$$\text{Fitness value} = \left(\frac{\left(\frac{V}{F_A}\right) - \left(\frac{V}{F_A}\right)\min}{\left(\frac{V}{F_A}\right)max - \left(\frac{V}{F_A}\right)\min}\right)^{x}$$

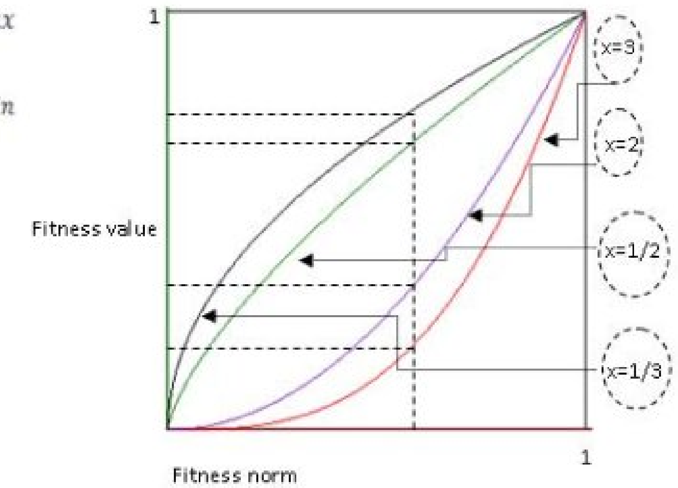


Fig 1 normalising the paramters

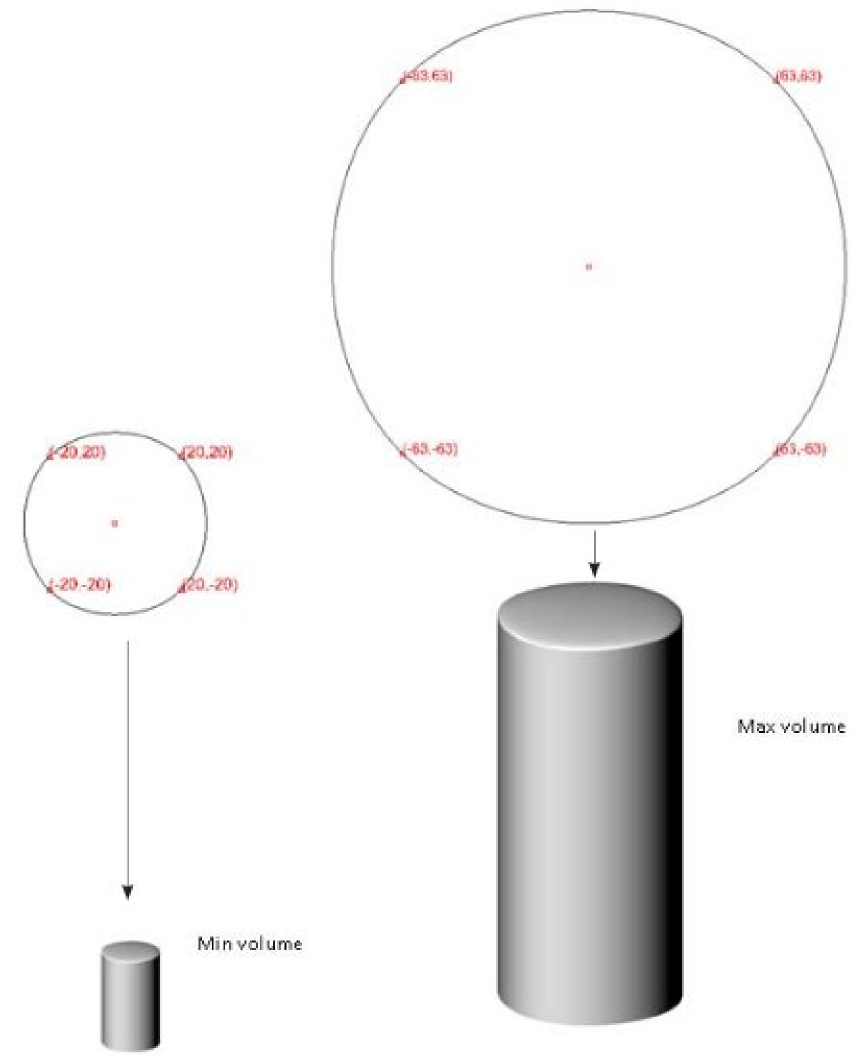


Fig 2 understanding the boundaries of the solution domain

Evolution

Fig2 shows the first and the last generation of one of the numerous experiments that have been run over the course of this research. What is clearly evident, looking at the picture, is the striking difference between traits of members of the 1st generation and the ones of the 30th generation. Although they all share the same topology the characteristics traits of the last generation can not be inferred from the ones of the first one. The final morphologies are the result of a continuous remodelling of the form of the individuals under the indirect influence of the fitness parameters. Their traits have not been consciously encoded but are the result of a process that starts with an abstract representation of their topology. After several generations it manages to translate the influence and the contrasting relations of the parameter that govern the evolution into shapes. Looking at the set of weights that has been assigned for this experiment, it can be seen that the influence of parameters concerning spatial organization such as "Height_of_Centroid" are dominant over the others. The height of the individuals of the 30th generation is bigger than the one of the 1st generation and the majority of them features a pronounced increase in volume along the height. In the majority of them the abrupt changes in the curvature featured by the individuals of the 1st generation are no longer present. The reason for that can be found in the influence of the above mentioned parameters whose main action is to favour the allocation of volume at the top side of the individuals as well as an increase in height.
Although this can be regarded as a successful result, the understanding of the influence of the fitness parameter and their interconnections have yet to be explored. The type of optimization that this procedure seeks to reach, does not lead to the fulfilment of the optimum for the parameters singularly taken. It tries to gain a balanced compromise between these which, most of the times, tend to balance out as the improvement of one lead to spoiling another one.
Consideration should also be given to the way I implemented the generative system. The developmental process is embedded in the algorithm and can not be subjected to neither modification nor evolution. The abstract representation of this topology that I first imagined and afterwards encoded in the developmental process allows, by means of evolution under certain design constraints, to generate a great variety of forms. Although this is true, the possibility for the developmental process to evolve , or better saying to auto-evolve, would lead to truly "emergent" configurations [11].

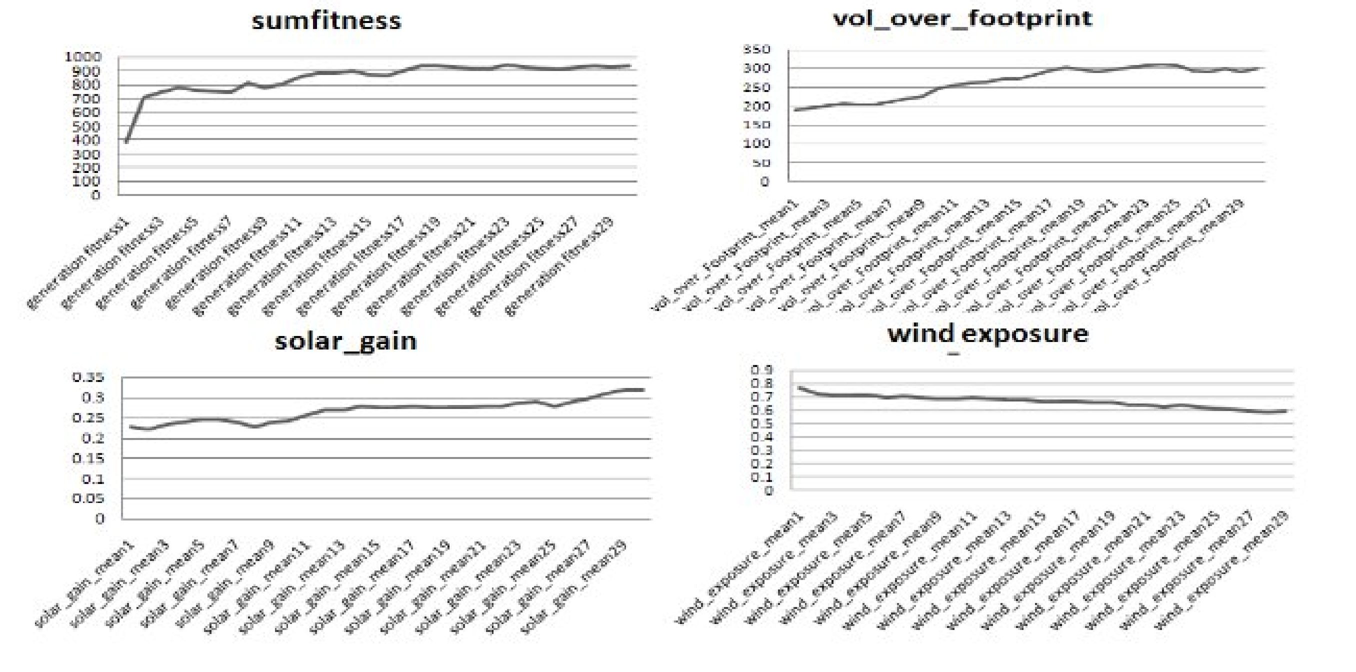
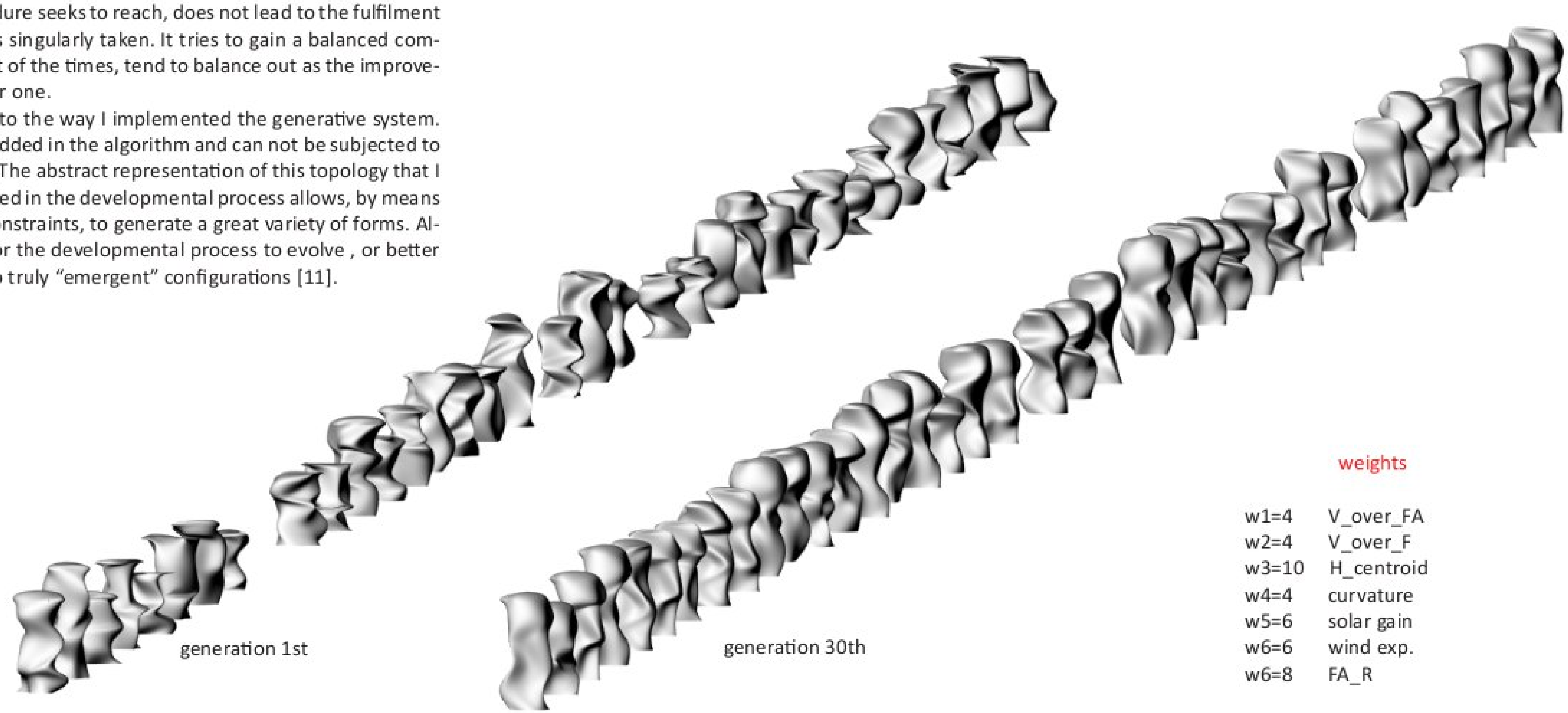


Fig 1 monitoring the fitness parameters



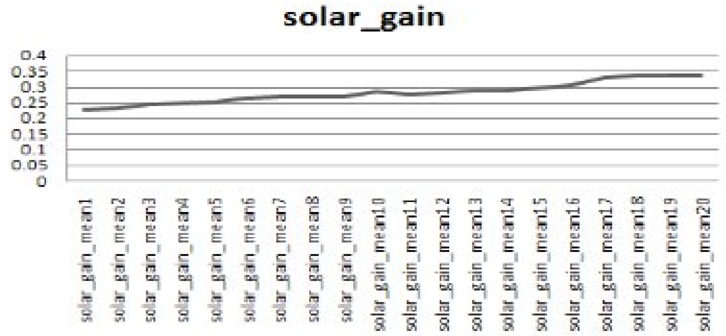
weights

w1=4 V_over_FA
w2=4 V_over_F
w3=10 H_centroid
w4=4 curvature
w5=6 solar gain
w6=6 wind exp.
w6=8 FA_R

Fig 2 generation over generation

Solar gain

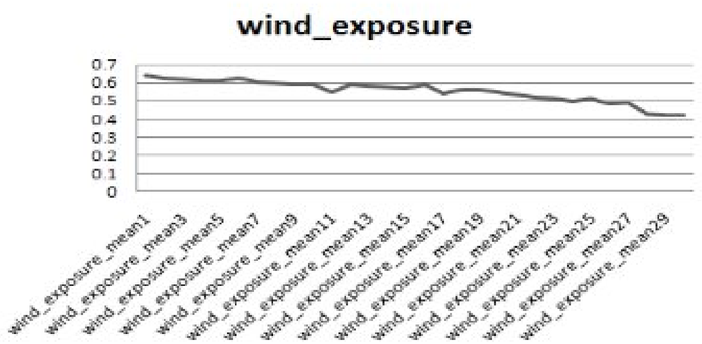
Fig1 show some of the individuals of the 20th generation for an experiment where all the fitness parameters , except the ones that concerns solar gain, are set to zero. At the and of the procedure they all have a morphology whose most relevant trait is to have the main dimension oriented perpendicularly to the mean of the directions of the sun(9a.m. to 3p.m. 21st of December) . This happens because they try to gain the highest value of solar detection possible within the size of their solution domain.



Wind exposure

It is here presented one of the member of the 30th generation for an experiment where all the fitness parameters, except the one that concerns the wind exposure ,are set to zero. At the and of the procedure the individuals present a morphology whose most relevant trait is to have a highly pronounced **"V-shape"** which is aligned with the direction of the wind(270 degree east). This happens because they try minimize the exposure to wind orienting their surface in order to avoid to experience high positive pressure. In this way we test the efficiency of the shape at not producing high value of positive or negative pressure which occurs mainly on the roof, lateral and back side of the individual respect to the direction of the wind (*fig1* bounding box represented by black dots).

Phenomena such as turbulence is only empirically taken into account, using the laws given by the ENV 1991-2-4, while vortex shedding is completely ignored. Although this shortcoming would make the procedure incomplete for an accurate analysis of a form exposed to wind flow, the procedure can be regarded as reliable for the scope of this research.



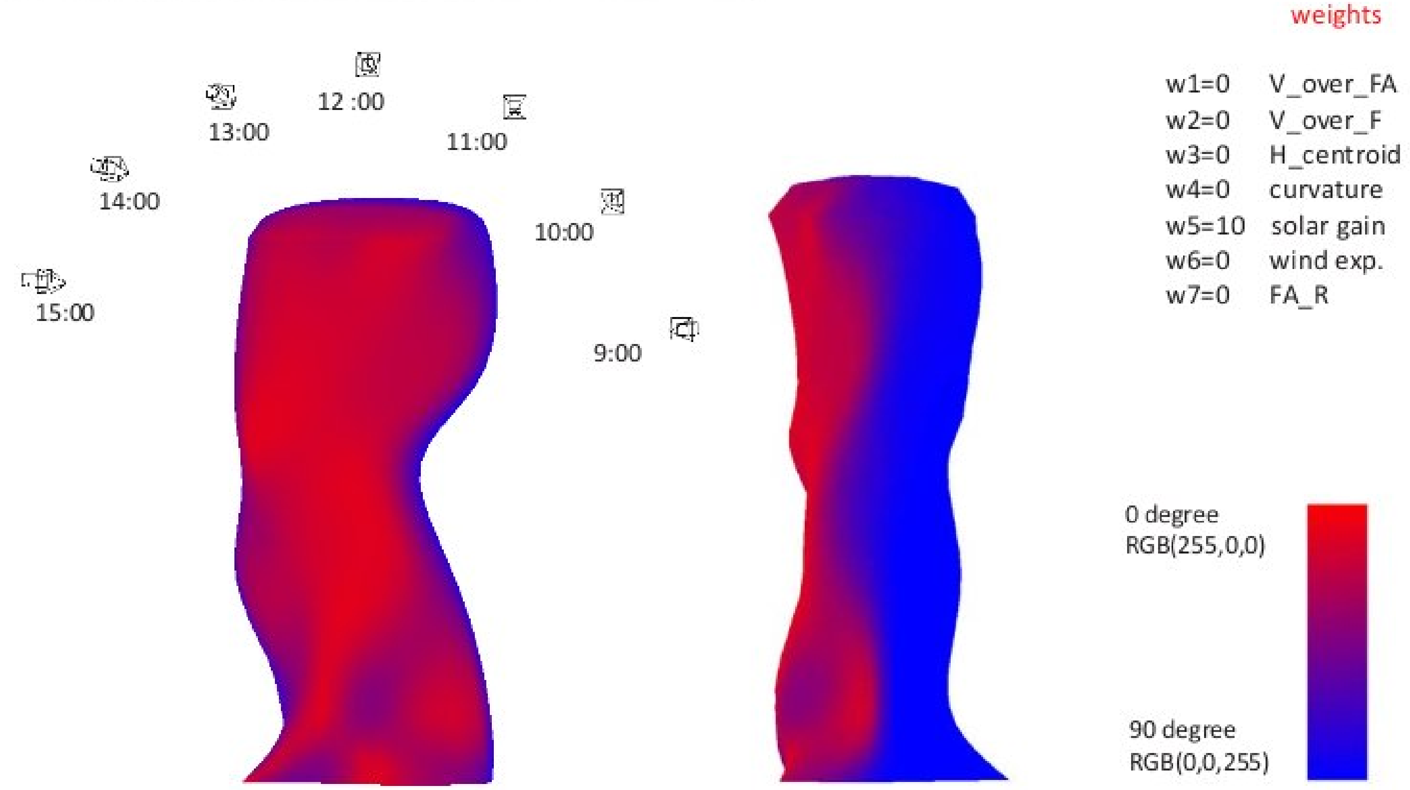


Fig1 south facing wall front view

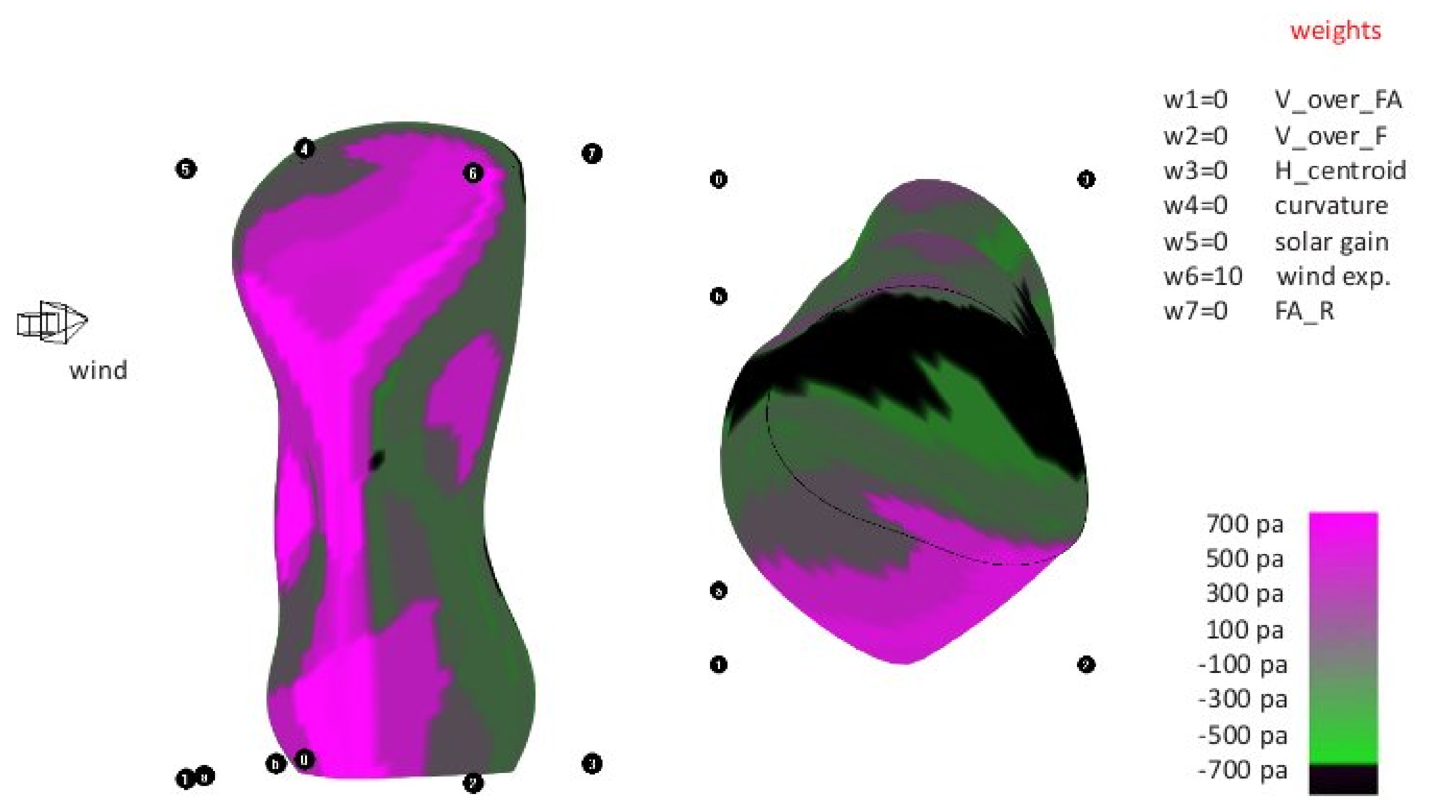


Fig2 upwind side top view

Varying the weights

The configurations here presented are obtained by combining all the available fitness parameters. *Fig2* shows a solution given for a set of weights where parameters concerning spatial organization such as "Height_of_Centroid" and "Wind_exposure" dominate the evolution *(run1)*. There are some traits that remind of the ones featured by members of the simulation shown in the previous page where only the "wind_exposure" were activated. The sharp appendices at the top aligned with the direction of the wind are the most evident. However, "wind_exposure" influence is here balanced by the other parameters that lead to morphologies presenting a higher position of the volumetric centroid and a smaller "Facade_to_Floors ratio".

Fig4 shows a configuration obtained starting from an equal set of random numbers (position of points which are the genes of the individuals) respect to the previous experiment but having this time a different set of weights *(run2)*. For this simulation spatial organization parameters are weighted to a greater extent, which is recognisable observing the morphology of the individual shown in *fig3*. The most relevant traits for it are a very high position of the volumetric centroid, a small Footprint area and smoothness of its envelope. It is worth saying that these two configurations are obtained stating from the same set of initial genes. However, the individuals are evaluated in two different environment, simulated assigning two different set of weights for the fitness parameters. This demonstrates to what extent the environment can influence their morphology. The tables below show the trend for the fitness parameters for *run1* and *run2*.

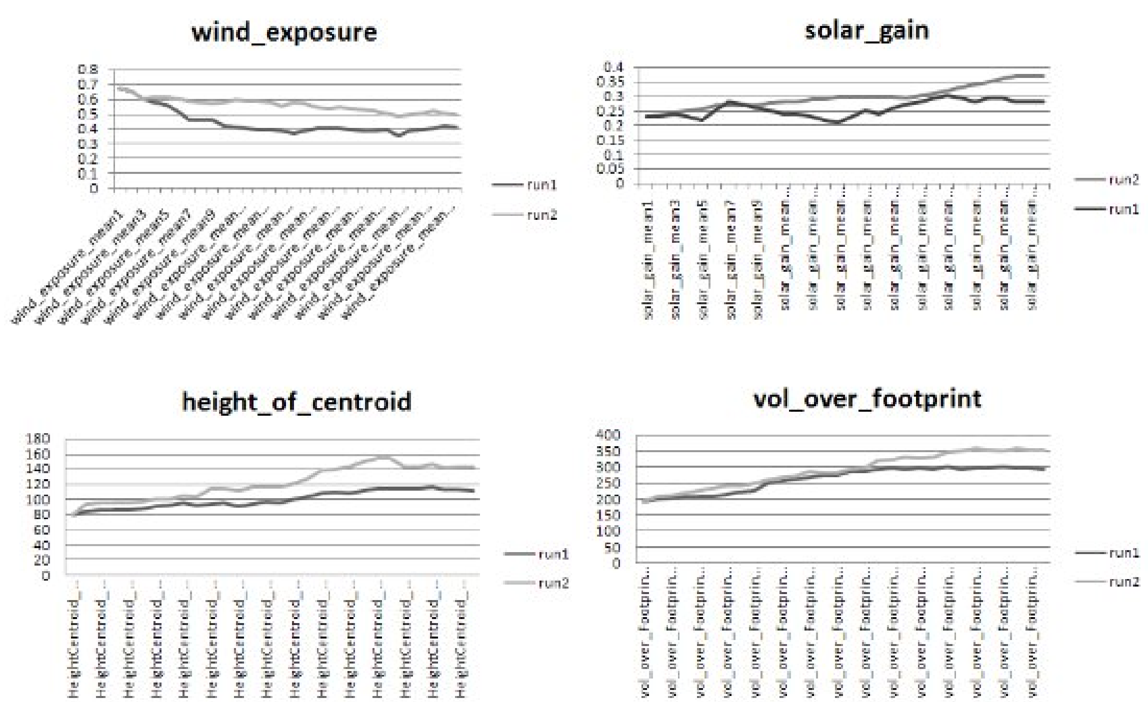
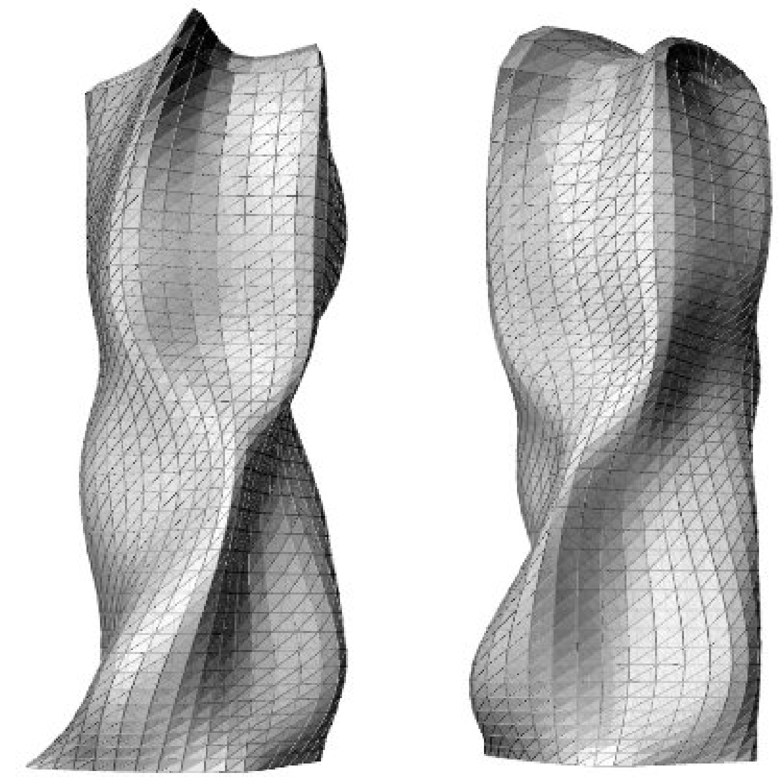
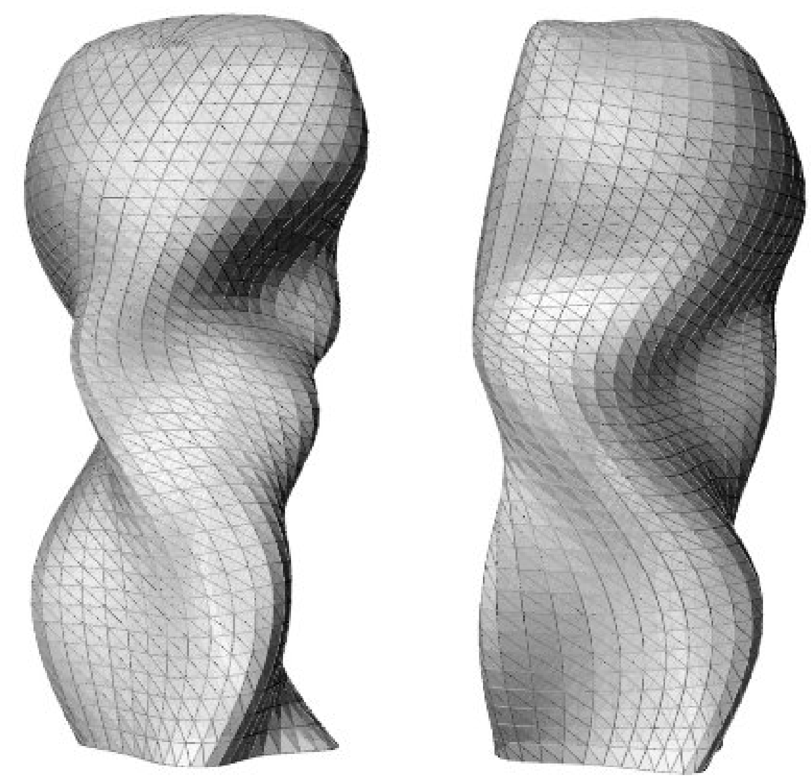


Fig 1 fitness trends for run 1 (darker lines) and run 2 (lighter lines)



run1	weights
w1=2	V_over_FA
w2=2	V_over_F
w3=10	H_centroid
w4=1	curvature
w5=2	solar gain
w6=10	wind exp.
w7=6	FA_R

Fig2 individual taken from the last generation of run 1



run2	weights
w1=3	V_over_FA
w2=5	V_over_F
w3=10	H_centroid
w4=5	curvature
w5=8	solar gain
w6=4	wind exp.
w7=6	FA_R

Fig3 individual taken from the last generation of run 2

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