Genetic algorithms applied to urban growth optimizing solar radiation

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ABSTRACT: In this work, parametric design is applied to improve solar radiation in an urban environment. The study case is located in a town in Buenos Aires Province. The current Building Code allows individual plots to be built with certain restrictions that produce an urban shape where environmental issues are not considered. The implementation of genetic algorithms to optimize solar radiation produces an alternative to the current urban model. The differences between both models are analysed. Recommendations for future designs are provided.
Keywords: solar radiation -parametric design- genetic algorithms

INTRODUCTION

This work analyses the application of genetic algorithms to parametric urban design in order to improve solar radiation. Parameterization allows the continuous control of the design process (1) and the evolutionary algorithms (2) optimize the required condition already mentioned. Here, we develop a simulation of urban growth according to current restrictions and building codes. The study case is a town situated in Argentine Pampa (3). This town, called Lincoln (4), bases its economy on soya crops. The cash flows, produced every year, are reflected in the economic growth. With these data, we build a model which encompasses the building growth. Our intention is to show how an urban block can grow differently if environmental criteria are applied.

These towns have experienced a fast growth during last years as soya prices began to rise (5). Urban development has occurred without any planning except for the current law that regulates the use of land, which was promulgated in the ´70s. This is the Decree- Law 8912/77 (6). This does not reflect environmental issues, such as the incorporation of renewable energies to buildings. In this case, solar radiation optimization is orientated to integrate solar devices to these buildings: solar collectors for SHW and PV modules. There is a wide range of uses in the town centre, where the highest density is concentrated for instance, commercial, housing and office buildings.

The comparison between the two models permits the urban designer to take into account solar radiation from the very beginnings of the codification process and to reflect this issue in the utilization of solar energy, making the necessary corrections to the current Building Code.

THE PLACE: CLIMATE DATA

Lincoln is situated -34°.8 S and -61.43 W. It is situated in zone III Template Warm, according to IRAM Standard n° 11603(7). Summer is relatively hot and mean temperatures are comprised between 20°C and 26°C with mean maximums over 30°C. Winter is not very cold; mean temperatures are comprised between 8°C and 12°C. Best recommended orientations are: NW, N, NE and E.

THE BUILDING CODE

The urban land is private except in case of public buildings. The owner must follow the restrictions and recommendations of the building regulations which refer to the plots as the units that form the urban block.

There are two coefficients that are applied to calculate the allowed surface that can be built in a plot: the Land Occupation Factor and the Total Occupation Factor. The current law referred to the use of land lets the owner to occupy, at maximum, 60% of the plot for the floor plan of the building. A 40% must be free for correct ventilation and daylight. This coefficient is called Land Occupation Factor (LOF).

The maximum built surface allowed can be from 1.2 times the plot´s surface up to 2.75. This coefficient is called Total Occupation Factor (TOF). It varies with the urban zoning and depends on where the plot is placed. In our case, as the block is in the town centre, TOF is 2.75. In order to simplify the process, each plot is divided into 6 modules. Four of them represent approximately 60% of the plot´s surface (LOF). Maximum TOF allows up to

16 modules, distributed in groups of 3 per floor, for plots in the middle of the block. It rises up to 18 modules distributed in groups of 4 in corner plots. Maximum height is 24m or approximately eight storeys.

TOF can be increased if the floor plan surface is smaller than the allowed by LOF. This coefficient also increases if the building is receding, leaving an open space in the front. These regulations promote to build higher receding buildings that shade over the lower neighbour ones.

Windows can only be opened in the front or rear façades. This restriction makes the buildings to occupy the plot from one side borderline to the other one. No lateral free space less than 4m wide can be left as it is considered that the building can only receive daylight and ventilation from the front urban space or the backyard**.** Dividing walls between different plots must not have openings for ventilation and daylight and therefore, they are blind. These walls cannot be affected by any use, e.g. PV panels. All these regulations make the buildings to configure a solid volume like a ring with an open space in the centre.

THE URBAN MODEL

We simulate five different states of growth: 50%, 55%, 70%, and 80%. These percentages are deduced from cash flow that comes from soya crops in the period from 2001 to 2007. We suppose that part of this capital is invested in building, as a percentage increment, with a delay of 3 years from the moment it comes into the regional economy. So we consider a period of time that comprehends from 2004 to 2010 (Fig. 2).

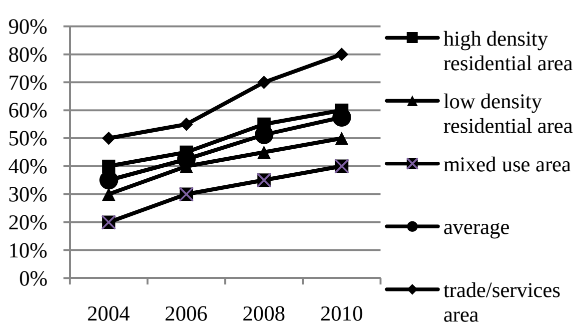

Figure 1: Investments according to building use

International crisis and domestic political failures interrupted this growth process and the results could not have been verified in the real scenario. However, the work evaluates a later stage with an 80% growth that eventually could occur.

Lincoln is divided into a rectangular grid oriented NE-SW. Unlike other Pampa towns, the grid is not square; it is only rotated 45° NE. This provokes that NE façades have best orientation (as we are in the Southern Hemisphere) but the remaining ones have not optimal orientations, especially the SW and SE ones (Fig. 2). Different kinds of blocks were analyzed from the town plan. They are shown in Fig. 2.

Type I has sixteen plots of 618m^2 each. The plots are divided into six modules of 103 m^2 each. Half the block looks NE and the other half looks SW. In the case of middle plots, the two modules in the backyard are left free to configure what is called “block-core”. This open space ensures daylight and ventilation to the rear façades. The buildings situated in the corner plots are not obliged to leave this open space as they have two façades looking to streets where to ventilate and get daylight. Type II has twelve plots of 412 m^2 and eight plots of 618 m^2. Four blocks look NE, another four look SW, six look SE and six look NW. Type III has twelve plots of 618 m^2, six looking NE and six looking SW. It has also six plots of 412 m^2, looking NW. Type IV is a mirrored image of Type III.

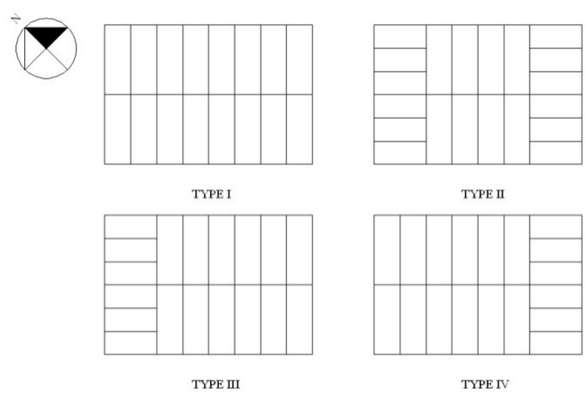

Figure 2: Different types of blocks in Lincoln town

METHODOLOGY

The main scope of the modelling is to optimize solar radiation for solar collectors (SHW) and PV modules. As the model tends to favour best orientations as the recommended ones by IRAM Standard 11604, the buildings are benefited as a consequence of the optimization of solar radiation.

The whole process is developed with Rhinoceros© 4.0. (8). Grasshopper (GH) (9), which is a Rhino plug-in, parameterizes the buildings and Geco (10) — a Grasshopper´s plug-in— links Grasshopper with Ecotect©. To improve these results, we run a GH genetic algorithm (11), Galapagos, connecting the inputs and maximizing the average solar radiation of the models. The best alternatives that can be obtained are shown and the designer can visualize the model in real time as the process is taking place. Ecotect gives accurate data about annual solar radiation of the best alternatives.

The input of the programme is a variable cash flow along a period of time which determines the volume to build. The distribution of the invested capital is according to town zoning (Table 1). It gives priority to higher density areas, favouring a concentration in the town core. This capital comes from agro-industrial exportations and part of this is supposed to be directed towards building activity. Our work hypothesis is that the urban growth would be distributed among the different zones with 22.5% as an average percentage in the period from 2004 to 2010. Commercial and service areas would grow more in the town core.

Table 1: Urban growth according to investments

Urban growth according to investments	2004	2006	2008	2010	net growth
trade/services area	50%	55%	70%	80%	30%
high density residential area	40%	45%	55%	60%	20%
low density residential area	30%	40%	45%	50%	20%
mixed use area	20%	30%	35%	40%	20%
Average	35%	43%	51%	58%	22.5%

The output of the process is the whole built volume of a block as it can be considered the unit in this level of urban tissue. Each plot is like a small individual but the sum of them configures a bigger entity which has emergent properties (13). We can refer to environmental conditions of these urban spaces as the results of the interaction of the different plots.

The parameterization of the modules allows a bottom-up method (12) to shape the entire building. The plots are divided in a grid of 6 modules. The modules to be built are randomly chosen to produce variation as it happens in the real world. Two are left vacant in the rear of the plot to allow ventilation and daylight that represent the 40% of free surface that must be left. From 2 to 4 modules— which is he maximum permitted— are picked up randomly for the plan floor. Another possibility is that the plot remains vacant. If more modules have to be built in a second floor, they are placed on the ones that are already placed in the floor plan to assure a tectonic structure. No modules in upper storeys can be placed on vacant modules in the floor plan. The same procedure is followed for the entire building. . The solar radiation for this simulation is shown in Table 2.

A simulation of urban growth corresponding to a type-I block is shown in Fig. 3. The growth corresponds to a 0.6 LOF and a 2.75 TOF. We have just applied the current Building Code. No optimization by means of GAs is executed. Private buildings are built according to their own needs, following current regulations. Some buildings are receding high volumes that do not benefit neighbours' solar radiation and leave a shaded urban space in the front of the building.

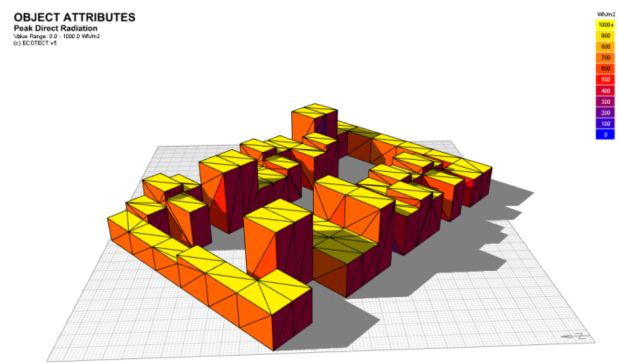

Figure 3 Type-I block: maximum growth without solar radiation optimization- shadows at noon, 22nd June

Table 2: Annual solar radiation from Ecotect analysis without GAs

TOTAL MONTHLY SOLAR EXPOSURE					
BUENOS AIRES, ARG					
Objects: 538 (Exposed Area: 26955.574 m2)					
	Avail.	Avg	Reflec	Incident.	
Month	Wh/m2	Shade	Wh/m2	Wh/m2	TOT.Wh
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Jan	256025	56%	0	88529	2386350592
Feb	208954	56%	0	70576	1902414976
Mar	196159	57%	0	65080	1754268672
Apr	157428	58%	0	48640	1311130112
May	130105	60%	0	38013	1024655296
Jun	100729	59%	0	30219	814568320
Jul	117655	59%	0	34141	920289728
Aug	137728	59%	0	43677	1177331456
Sep	171622	57%	0	54967	1481663872
Oct	200279	56%	0	69669	1877967488
Nov	229007	57%	0	79945	2154964480
Dec	238722	56%	0	84509	2277990912
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Total	2144413		0	707965	19083595776

After obtaining the simulated growth for each stage, we proceed to add solar radiation as a variable that could modify the building shape to optimize solar radiation.
We introduce a genetic algorithm which output is the arrangement of the modules, randomly chosen according to a 0.6 LOF and a variable height to achieve a 2.75 TOF. Different arrangements are obtained. There are

many possible assemblages, occupying from two to four modules in the floor plan with different heights (fig. 4). The maximum height allowed is 24 m (approximately 8 storeys). If this height limit were higher, volumes on NE side would project shades onto the rear façades of the SW plots and these would not collect enough solar radiation as it is shown in Fig. 4.

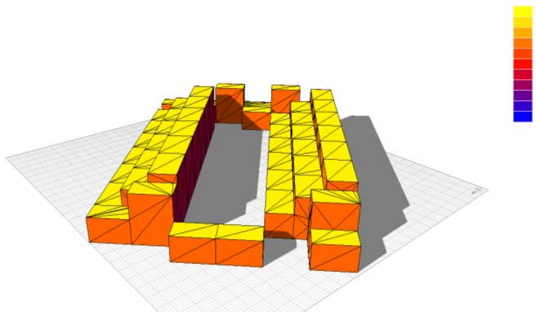

Figure 4 Type-I block: maximum growth with solar radiation optimization- shadows at noon 22nd June

In Table 3, the incident radiation, 798,644 Wh/m^2, is higher than in the first simulation, 707,965 Wh/m^2 (Table 2). The quantity of modules is the same for each case. But the exposed surfaces differ from each other. In the second case, the exposed surface collects more radiation per square meter. The increment between the two models is 9.2% according to Ecotect analysis. The average value obtained by GECO is 510.50 Wh/m^2 for the first case and, 557.73 Wh/m^2, in the second case.

Table 3: Annual solar radiation form Ecotect analysis with GAs

TOTAL MONTHLY SOLAR EXPOSURE					
BUENOS AIRES, ARG					
Objects: 484 (Exposed Area: 25096.502 m2)					
	Avail.	Avg	Reflect.	Incident	
Month	Wh/m2	Shade	Wh/m2	Wh/m2	TOT.Wh
-------	--------	------	--------	-------	------------
Jan	256025	53%	0	96182	2413822464
Feb	208954	50%	0	77660	1949000832
Mar	196159	50%	0	73770	1851361920
Apr	157428	48%	0	57566	1444701184
May	130105	48%	0	46041	1155457536
Jun	100729	44%	0	36086	905628864
Jul	117655	45%	0	41492	1041306112
Aug	137728	49%	0	51359	1288927872
Sep	171622	49%	0	63906	1603826176
Oct	200279	51%	0	77207	1937632512
Nov	229007	53%	0	86769	2177596928
Dec	238722	53%	0	90607	2273909504
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Total	2144413		0	798644	20043169792

The augmented radiation is only due to changes in the shape. One of the best prototypes obtained is the terraced one (fig. 4). This shape is applied to NE and SW sides. Corner plots on NW side remain low and on SE side are higher.

RESULTS

As it can be observed in the first simulation (fig. 3, Table 2), the current Building Code rules certain parameters as the maximum volume to build, maximum height, distance from front and rear plot borderlines to façades and the amount of free space, among other variables.

However, there are no specifications about incident solar radiation in order to improve daylight or integrate solar devices to the buildings, like solar collectors for SHW or PV panels. When that parameter is considered, some regulations lose sense like the increment of TOF if a smaller surface than maximum LOF (60%) is occupied, or if the building leaves a free space in the front of the plot. The increment of TOF permits more storeys up, which provokes to appear isolated high buildings in a low-rise urban tissue. These buildings not only break the skyline, but avoid low-rise buildings to get access to sun. No solar envelope (14) is considered in the Code and some plots are in serious disadvantage to get direct solar radiation. There is also no difference between the different orientations of plots in the block. No matter which orientation they have, all plots are considered in identical way. The results show that, for current regulations, any orientation and placement in the block is the same. When too high-rise buildings looking NE are placed receded from the front borderline, buildings that are placed on SW side, cannot get enough solar radiation on their rear façades (fig. 5 and 6).

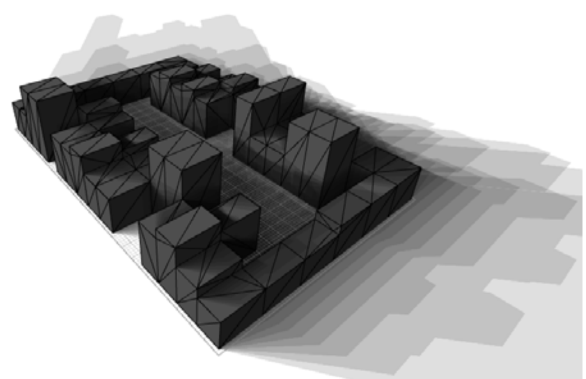


Figure 5 Type-I block without GAs optimization showing shadows on SW plots rear façades when high NE buildings are placed receded from front borderline

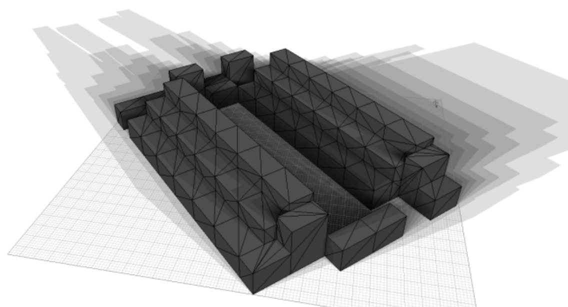


Figure 6 Type-I block with GAs optimization: terraced buildings on NE and SW façades, low rise buildings on NW and high rise ones on SE sides

When GAs are applied, not only incident radiation on façades improves, but also the open spaces have better access to solar radiation. The volumes on the NE plots are placed next to the front borderline to avoid leaving a vacant space. They are terraced to gain solar radiation. The backyards are not affected as this line of volumes is not high enough to project permanent shades on them. The volumes in the SW plots have their maximum height on the front borderline to allow their backyards and back façades receive direct radiation by means of terraces. Buildings on the SE plots have the higher volumes on their front borderline to allow solar radiation onto the lower volumes. This shape lets solar radiation into the core of the block.

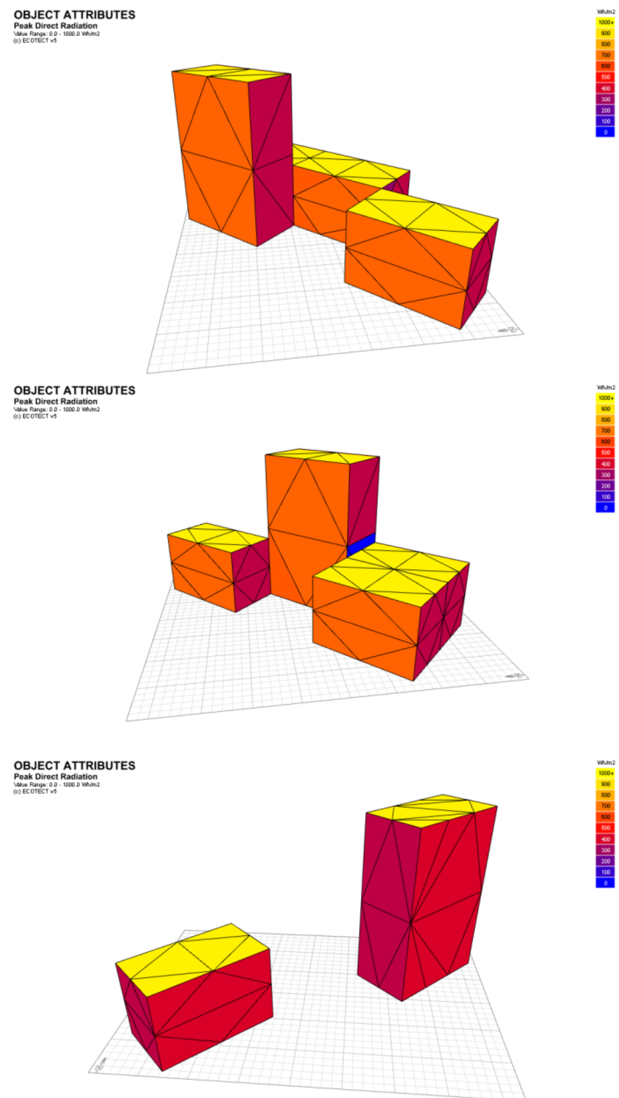
Some of the possible solutions for a SE corner plot are shown in figs. 7, 8 and 9. The best of each type were chosen for constructing the model. General recommendations for 45º rotated urban grid can be inferred from this research.

It is recommendable for:

- every orientation: no receding buildings
- NE plots: lowest height on the borderline, terraced façades towards the rear of the plot.
- SW plots: highest volumes on front borderline, terraced towards the rear of the plot.
- NW: maximum land occupation (60%) and low rise volumes
- SE: higher volumes to collect enough solar radiation

TOF coefficient should no longer be increased if LOF is reduced. This makes the floor plan become smaller and the building, higher. When this happens, there is less surface to allocate solar collectors. The shades that these high volumes project, worsen the low-rise building situation, affecting their possibilities to install solar devices.

If the building is receding, the situation adds another problem that is a shaded front urban space. Front receding façades receive less solar radiation if the neighbour buildings are placed just on the front borderline, projecting shades on them (fig. 5).



Figs. 7, 8 and 9: optimized arrangements for a SE corner plot using GAs

For this kind of blocks, maximum height should not overcome eight storeys or approximately 24m because the projected shades would invade the neighbour blocks facades, as can be observed in fig. 5.

CONCLUSIONS

One of the scopes of this work is to think urban shape as a result of the interaction of minor units (plots) which are modelled by the regulations. This bottom-up method avoids thinking the city as the abstract structure tree (15). The mixed use that is found in the town core assimilates better to a semi-lattice rather than a tree.

With the application of GAs to the parametric process, the solar radiation average can be improved by managing volume arrangement. Specific regulations on each plot are needed and not a general rule for every plot as in the current situation. Orientation must be considered a priority. Better shaped buildings can be promoted by means of tax exemption if these regulations are fulfilled.

Another issue that should be reconsidered is the use of the dividing walls between the plots. The current law does not allow opening windows on them, as they must be blind. If those walls could be used to place PV modules, it would notably increase the available surface to collect solar radiation.

The specific recommendations (e.g. number of storeys) are only applicable to this case. Each particular urban tissue has different restrictions based on block geometry and plot dimensions and orientation. The inclusion of environmental issues in current building codes is absolutely necessary if there is any intention to integrate solar water collectors or photovoltaic modules to buildings.

As it can be observed, parametric design allows getting control over size, shape and placement when designing buildings in urban environments. It is a valuable tool for modelling urban landscape and improving environmental conditions.

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