A City Simulator

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Abstract

This paper presents a new computer model for city skyline simulation. It works by shaping medium and high-rise buildings to their best performance. This new tool was conceived to simulate and analyze cities where tall buildings are emerging on pre-existing urban schemes with irregular geometry and where inter-building spacing is proportional to the height of built blocks.

The model is based on two main inputs, namely: the description of the network formed by land subdivision of the actual or irregular urban schemes, and the building regulations quantitative parameters based on solar obstruction angles *and maximum usability rates*.

By combining data from these inputs, the computer model presents the dimensions of the building envelop for maximum profitability of each plot. That way the architect will immediately know the number of floors that leads to the maximum built area, for certain plots. In addition to this, the built blocks images are presented in the screen, as well as corresponding tables and Cartesian graphs.

Furthermore, this model can also be used for analyzing city skyline for large urban areas. This analysis can range from a mere visual inspection of the variety of images built blocks will take under different legal constraints, to a more intricate analysis of how city skyline and built area, amongst others, are affected by different the regulations.

Keywords

Computing City Shape, Land use performance, Computing city skyline, Urban network design, Computing City Architecture.

1 Introduction

The present paper contains applications of a new software created for profitability analysis of plots, when submitted to legal constraints in respect to the needed inter building spacing based on solar obstruction angles.

The analysis presented here, focuses on seven plots selected from an irregular urban scheme with 70 plots of varying sizes and shapes, where high rise buildings are replacing pre-existing dettached houses. At each of the seven selected plots, we have looked at three main performance measures: the built to plot area ratio, the built to open area ratio and the built to facade surface ratio.

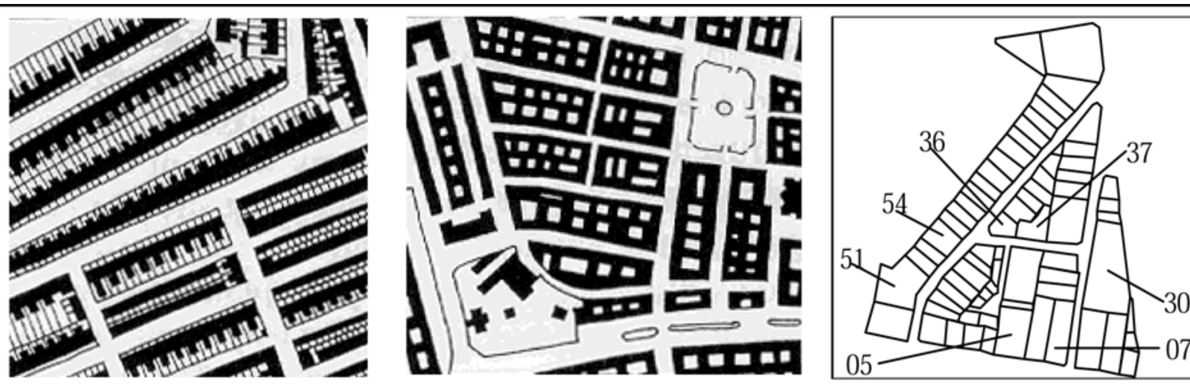
From a number of simulations, it was observed that: there is a simultaneous relation between the geometry of plots and urban blocks, in respect to the size and shape, which determines the optimum urban design. Planners must, in their urban design, pursue or seek the equilibrium point that produces, at the same time, the best profitability on the use of land and the most comfortable obstruction angles.

1.1 The Geometry of Town and Cities

It is common sense that all cities are made of plots (micro-cells), urban blocks (macro-cells) and lines of access required to them. These lines converge and cross each other, therefore, cities are analogous to a network system, with lines, nodes and cells, formed by the mesh resultant from the land subdivision and access lines. Cities may vary not only according to the configuration of its network system, but mainly according to the way architecture relates each building to its cell or domain area (the plot).

Some buildings develop around the perimeter of its cell, as a torus (donut) or a ring-shaped object where the nucleus is an empty open area. This perimetral typology can be seen on urban blocks as well as on plots. Built blocks along the perimeter of urban blocks is the most frequent type found in traditional cities, as for instance, the terraced houses side by side forming a ring along the perimeter of urban blocks. In the same way, built blocks along the perimeter of the plot is the typology of patio buildings found in Berlin and patio houses in Muslim cities.

Traditional cities tend to show a horizontal outline and the only tall building to be found on them are defense or symbolical towers, minarettes and similar. Nevertheless, the most recent mega cities tend to have a vertical outline with high rise buildings located in the nucleus of its cells (plots), leaving a ring-shaped open area around them. The most famous exception is New York, which is a vertical mega city built on a perimetral structure, which is peculiar to traditional cities.



Regular housing scheme in London where buildings on individual plots, side by side, form a built block developed around the urban block perimeter.

Irregular housing scheme in Berlin where patio buildings are developed along the perimeter of each plot

Irregular scheme in Recife where plots show a variety of size and shapes and where pre-existing houses are being replaced by tall buildings on the nucleus of each plot

Figure 1. Housing schemes in different cities.

Similarly, the nuclear occupation can be seen either in center of plots or in the middle of urban blocks. Recently, this nuclear typology was first applied to houses in garden cities and later to the tall buildings, built after the modernist principles put forward by the group of Le Corbusier in the Charte d'Athenes, at CIAM in 1929. In spite of the fact that the modernist paradigm has been nowadays an object of criticism, vertical cities with tall buildings are emerging everyday and everywhere on pre-existing urban fabrics.

From Gropius (1929) to Martin & March (1972), comparative studies on the best use of land for these two typologies (perimetral and nuclear) have been made with significant results. They have answered important questions, such as: the optimum profitability of land can be achieved without necessarily the presence of high-rise buildings. Martin & March wrote a number of seminal articles and in one of them, entitled The Grid as a Generator, they suggest that the configuration of the land subdivision and lines of access affect the density of construction. Raymond Unwin (1910), was the first author concerned with the economy of the roadways and the length of other urban networks, when he was in charge of planning garden suburbs and some of the early English new towns. Following this concern, the WORLD BANK charged Caminos & Goetthert to produce a study entitled Urbanisation Primer (1976), where the performance of urban networks is measured for one site with a variety of alternative urban schemes. They've concluded that the design of urban layout affects the performance of urban networks.

1.2 The Geometry of Modern City and New Regulatory Tools

According to Gropius, vertical cities built after modernist principles need new regulatory tools based on obstruction angles that determine the solar incidence on all rooms in which human permanence is expected. Since then, the rule imposes that the taller the buildings, the bigger the setback '*s*' between them. These are considerations to preserve environmental quality. Nevertheless, the society and market forces add to these other considerations of utilitarian nature, as for example the one that imposes the rule: 'the greater the number of square meters built per surface of land, the greater the number of people can be housed with less cost'.

In order to preserve the environmental quality, the distance between tall buildings must be calculated as a function of the height. There is a canonical form which gives the metrical dimension of the setback '*s*' between a prismatic building and the boundary of its domain area, which can be expressed as $s = a + (n-b)m$; where '*n*' stands for the number of floors, *a*', '*b*' and '*m*' are constant parameters, where '*a*' is equivalent to the width of a '*non aedificandi* ring-shaped area along the perimeter of the plot, '*b*' is equivalent to the number of non counted floors, for garages and ground floor,

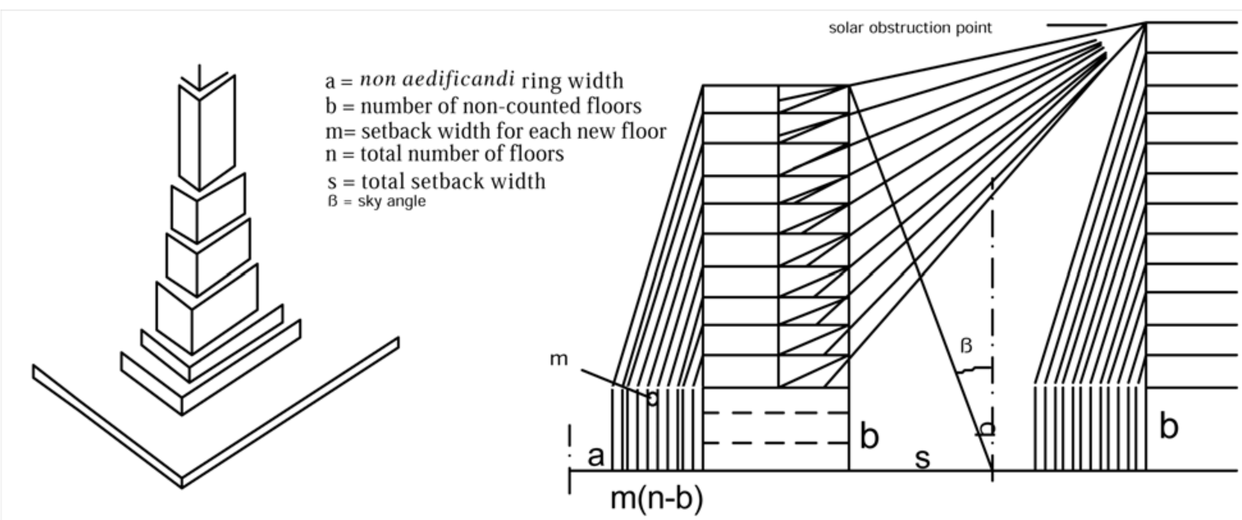


Figure 2. The tall buildings and the rule of progressive setback

and '*m*' is equivalent to the setback required as each new floor is added above a certain number '*b*' of non counted floors. The parameter *'m'* should vary with actual solar angles, thus, it is dependent on the block orientation, such as, North South or East West, but, for the present simulation it will be taken as a fixed value. As is the case of urban regulations in many cities.

The utilitarian consideration on profitability of the site can be represented by the usability of the land, which is the ratio of the built area '*B*' to plot area '*P*', or '*B/P*'. There is another utilitarian consideration related to the urban network performance, which can be represented by the ratio of the built area '*B*' to service lines length (or urban network length) '*L*', or '*B/L*'.

Finally, considerations on environmental quality, given by the setback rule, must be related to the considerations of utilitarian nature, given by the usability of land and networks. Nevertheless, the introduction of all these parameters to the urban analysis on actual schemes (with irregular geometry) leads to more complex mathematical calculations required to find the optimal built area for different network configurations assumed by the land subdivision and roadways.

The following chapters present applications, both on notional and actual urban schemes, and as it will be seen all these variables and parameters are interrelated.

2 The Optimum Size and Shape of Buildings in Regular Layouts

Taking into consideration setback laws of the type $s = a + (n-b)m$, as mentioned above, which determines the distance *s* between buildings as a function of the number of floors *n*, and assigning constant values to parameters *a*, *b* and *m*, (such as,. a=5, b=4 and m=0.5) a simple question related to the configurations in figure 3 could be asked:

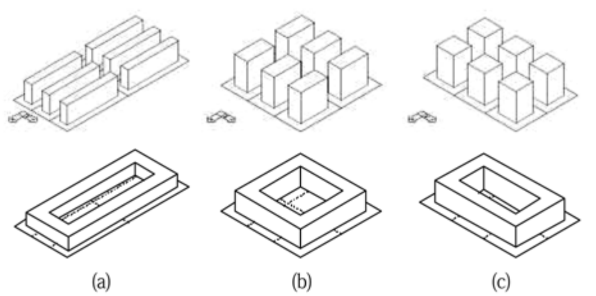


Figure 3. Layouts with 6 equal sized plots, nuclear and perimetral typologies

1) What is the number of floors that gives the maximum built area at each plot? Which one of the plots provides the highest profitability for the construction area and uses, at the same time, the least amount of city roadway?

Moreover, it must be noted that in figure 3, the rectangular plots and urban blocks, with equal size but different proportions, form a regular planned scheme. Nevertheless, real cities present more complex situations, as these may not have planned layouts, with equal regular plots forming the urban blocks and equal urban blocks forming the urban mesh. In fact, actual cities are likely to have irregular layouts, with different plots in the same urban block, and different blocks forming the urban mesh. So, another simple question can be considered, this time observing the urban mesh in figure 4:

2) What is the maximum built area possible at each urban block? Which one of the urban blocks provides the highest profitability for the construction area and uses, at the same time, the least amount of city roadway?

In this context and following an inverse rationale, one could ask, as well: how long and deep should a plot be in order to get the best use of land and urban networks for a certain built block?

One could try answering the questions above, either by calculation or design process, but it may take some time to get these answers manually using a trial and error process. A computer model for simulating the geometry of tall buildings in actual irregular-shaped cities has been conceived to help on answering these questions in a very quick way. A simple illustration of the questions tackled in this work is included below.

Take, for instance, three notional sites, one-hectare in size, divided into six notional rectangular plots of different proportions, as in figure 3. Around the boundary of each plot there must be a *non-aedificandi* ring of setback, 3.0 meters width, for example. Consider a setback rule that imposes for each added floor - above the three non counted floors - a 0.5 meter setback must be added to that initial 3 meters width of the *non-aedificandi* ring.

The built blocks shown in the three diagrams are those that maximise the built area when parameters for the setback rule and maximum usability are applied.

Despite the fact the same setback rule is applied to equal-sized plots and equal-sized urban blocks, table 1 show that the number of floors and the profitability of land and roadways are different for the three schemes a, b and c: they've reached 7, 11 and 12 floors, respectively. The best use of land and best performance of roadways is achieved by the scheme c. The first scheme with seven floors is the one which presents the best obstruction solar angle; therefore, it is the most comfortable in respect to environmental aspects.

Once the maximum built area and the corresponding number of floors are obtained for the nuclear building (or pavilion), it is possible to obtain the number of floors required for a peripheral building (or court) with equivalent surface. As the width assigned for the peripheral building is 12 meters and the built area remains the same as previous, the number of floors in site 'a' will be 5, in site 'b' will be 7 and in 'c' will be 8. The solar angles are more open than in the previous typology, as can be seen from the resultant urban landscape shown in the lower part of figure 3.

Nonetheless, in case the notional sites taken were double-sized (or two hectare) and subdivided into twelve plots, with equal size and shape as the previous plots, the best performance of roadways would be achieved no longer by scheme c, but by the scheme b. This mobility of performance according to the size and shape of macro and micro cells, shows that the influence of the size and shape of urban blocks on the performance of urban networks is as significant as it is the influence of the size and shape of individual plots.

3 A New Software for the City Skyline Analysis

When sites are geometrically irregular, it is not easy to control an experiment to measure the influence of size and shape of irregular plots and urban blocks. In view of this fact, how can planners measure the performance of irregular urban layouts, where blocks are made up of plots of different sizes and shapes? How can planners proceed for the joining or splitting of plots in irregular shaped sites? How could they propose size and shapes for new plots and urban blocks for new sites limited by natural features or non-rectilinear roadways?

In view of the complexity of the geometry of modern cities, city planners need now new tools for a more efficient architectural and urban design. The new tool must describe the actual urban fabrics involving the geometrical irregularities of the network made up by the land subdivision.

4 The Optimum Size and Shape of Buildings in Irregular Layouts

This chapter presents applications of the software on plots number 5, 7, 30, 36, 37, 51 and 54 selected from an urban scheme shown in figure 1. Figure 4 shows 3D images of the two typologies of built blocks – the peripheral and nuclear. Cartesian graphs present the variation of built area, built to open area and façade area (y-axis) against the variation of the height of block (x-axis).

The relation between the maximum possible built area and the plot area reflects the land use perfor-

Table 1: Urban usage of notional plots, schemes a, b and c.

	Totals						Average				
Scheme	No. of plots	Coverage area	Open area	Plot area	Built area	Façade area	No. of floors	Built to open area	Façade to built area	Floor to plot area	Built to plot area
a	6	3348	6552	9900	23436	17892	7	3.6	0.8	0.33	2.4
b	6	3168	6732	9900	34846	19404	11	5.2	0.6	0.32	3.5
c	6	3081	6821	9902	36774	19526	12	5.4	0.5	0.31	3.7

mance. Similarly, the built to open area ratio indicates quality of life in respect to open space, and the façade surface to built area ration indicates the degree of compactness of the built block, which certainly affects the costs of the building.

When using this model, the first input required by the software is the dimension of the sides and internal angles of each plot. Both, dimensions and angles may be entered by drawing or by a numerical process. The second input required are the regulatory parameters, which are related to the local building regulations. Following the modernist principles on solar obstruction angles, put forward by Gropius, you must introduce the rules for the initial setback corresponding to an initial number of floors and also introduce a new setback for each new floor you add on the built block. In cities where you have any other legal constraint, as for instance, on maximum built area, occupancy rate or maximum height, you must also enter these constraints.

After processing the entered variables and parameters the software outputs results on the screen in form of tables, graphs and corresponding images. The main output is the number of floors that gives the maximum built area with the 3D images showing the built blocks at that height. Graphs appear on the screen showing curves representing the variation of the potential built area against the variation of the number of floors.

More inputs, to refine the building characteristics of each specific plot, may be entered and processed by the software. As you enter the surface of each flat you intend to build, the curve for legal or potential built area shifts its smoothed appearance to a broken line, which stands for the actual built area (figure 4, 1rst column). Its higher point indicates the number of floors where actual built area occurs. New inputs related to the number of garages per flat and its corresponding area may also be introduced. According to local rules of Recife, the garage area will be added up to the potential (or legally permitted) built area. Finally, entering the unitary cost per square meter for the flats, for the garages and for the façade surface, leads to an estimate of the total building costs.

5 Analysis of seven plots submitted to fixed setback parameters

Looking at the 3D images of both typologies of built blocks in figure 4, it is easy to see that the only plot in which peripheral typology reaches the same height as the nuclear or central typology, is plot 30. This fact apparently contradicts Martin & March theories that central typologies (or pavilion) tend to be taller than peripheral type of buildings (or court). Nevertheless, this is due to the fact that plot 30 is far larger in size than the rest of plots. And, as the setback rules parameters have been equally applied to all of them, the constructive potential had to be constrained to a maximum of four times the plot area. Otherwise, the built area would be higher than permitted by the regulations (figure 3, 1st column).

For a comparative study, the model offers another set of graphs and tables that permit a more accurate view of the city skyline analysis. In order to proceed with the comparative study, all plots should be under the same setback rule already applied, where m=0.5; and again, each variable in y-axis is analysed against the number of floors in the x-axis.

5.1 Analysis of three individual plots of irregular shape

Now, the analysis can go deeper in detail focusing only three plots, 36, 37 and 54, selected from the borough as shown in figure 1.

Numbers, in the table 2, show that, in spite of the fact the area of plot 37 is bigger than the one of plot 54, the built area in plot 37 is less than that in plot 54. In the same way, the built area in plots 36 and 37 is the same, but the surfaces of the two floors are 651.2m^2 and 816.6m^2, respectively. Therefore, the bigger built area does not always correspond to the bigger plot area.

In respect to the ratios 'built area to plot area' and 'built area to façade surface', the more efficient building is that on plot 54, the second is on plot 36 and the least efficient is on plot 37. This means that in case the three plots were for sale at equal prices, a decision should not be taken simply based on size criteria. Other criteria, such as, economy of façade surface, constructive poten-

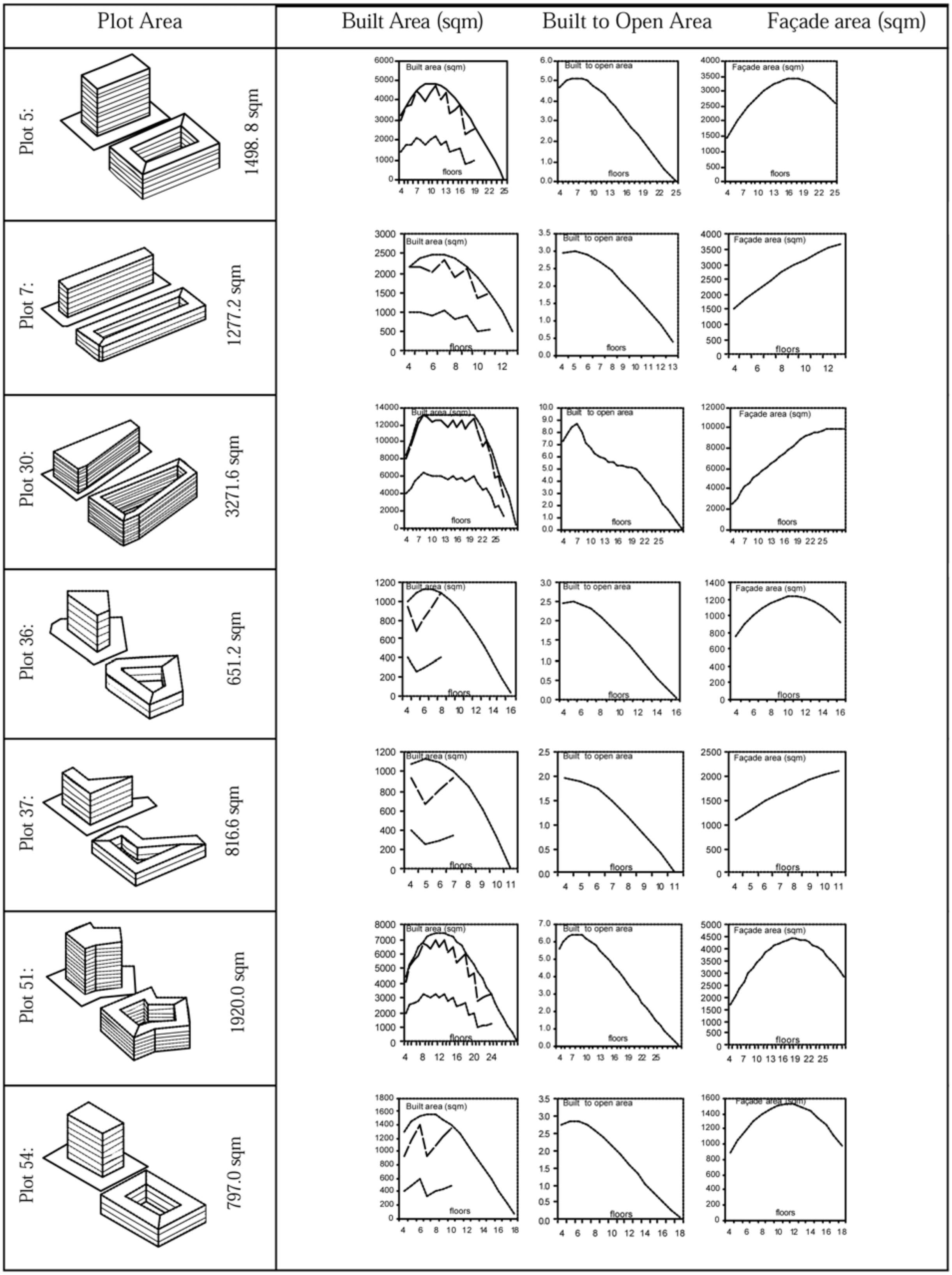
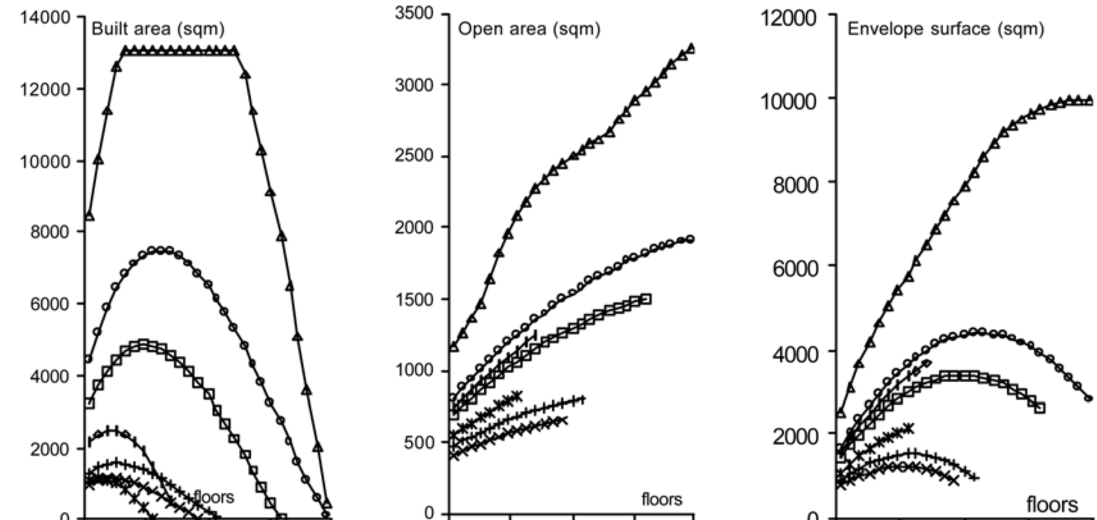


Figure 4. 3D Building Images and Corresponding Graphs



Built area (sqm)

	4	11	18	24
5	3221.8	4832.3	3084.5	476.7
7	2157.1	1503.6		
30	8450.6	13087	13087	9154.3
36	988.20	796.60		
37	1080.3	8		
51	4466.3	7461.4	6160.8	3254.2
54	1305.7	1276.7	67	

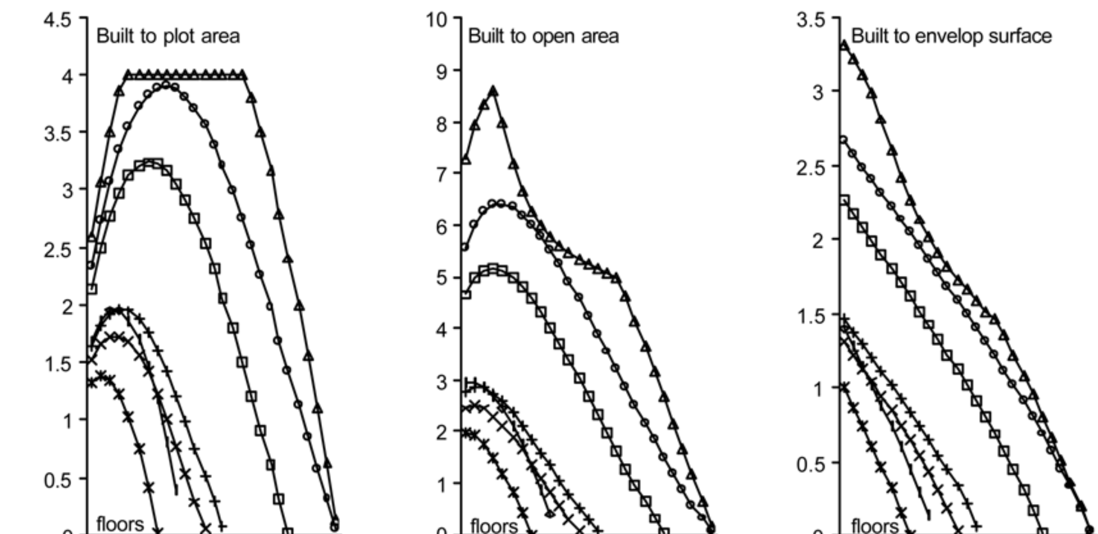
Open area (sqm)

	4	11	18	24
5	693.43	1059.6	1327.5	1479
7	737.93	1140.5		
30	1159	2081.9	2544.6	2890.2
36	404.15	578.78		
37	546.49	815.83		
51	803.43	1241.7	1577.7	1784.4
54	470.58	680.94	793.28	

Envelope surface (sqm)

	4	11	18	24
5	1423.7	2989.3	3376.3	2770.1
7	1541.2	3353.1		
30	2546.8	5773	8254.3	9648.7
36	751.60	1226.3		
37	1083.3	2100.2		
51	1677.9	3650.3	4396.1	4059
54	889.3	1521.3	977.1	

Figure 5a. Comparative analysis of architectural and urban indicators for 7 plots



Built to plot area

	4	11	18	24
5	2.1495	3.2239	2.0579	0.318
7	1.6889	1.1773		
30	2.583	4	4	2.7981
36	1.5175	1.2233		
37	1.323	0.0098		
51	2.3262	3.8861	3.2088	1.6949
54	1.6383	1.6019	0.0841	

Built to open area

	4	11	18	24
5	4.6462	4.5606	2.3235	0.3223
7	2.9232	1.3184		
30	7.2915	6.2857	5.1429	3.1674
36	2.4451	1.3763		
37	1.9768	0.0098		
51	5.5591	6.0091	3.9048	1.8237
54	2.7747	1.8749	0.0845	

Built to envelop surface

	4	11	18	24
5	2.263	1.6165	0.9136	0.1721
7	1.3996	0.4484		
30	3.3181	2.2668	1.5854	0.9488
36	1.3148	0.6496		
37	0.9972	0.0038		
51	2.6618	2.0441	1.4014	0.8017
54	1.4682	0.8392	0.0686	

Figure 5b. Comparative analysis of architectural and urban indicators for 7 plots

Table 2: Description of built blocks which maximize the built area in the each plot

Plot	Plot area	Built area	Floor area	Open area	Façade area	No. of floors	Sky angle	Built to plot area	Floor to plot area
36	651.2	1129	161.3	489.9	1086	7	17.2	1.73	.25
37	816.6	1129	225.9	590.7	1297	5	20.1	1.38	.28
54	797.0	1569	224.3	572.7	1304	7	17.2	1.97	.28

tial, number of floors and open area per built square meter must also be analysed.

Another indicator of quality of urban design is the sky-angle ß, which is formed by a line (or solar ray) connecting the upper part of the built block to the lateral boundary of its plot (figure 2). Table 2 shows that the height of building and the sky angle are not related to the amount of built area. So, it is possible to get the best use of land with more open sky angles, which is peculiar to lower rise buildings. This conclusion conforms to Martin & March theories. And it is very significant for planners in charge of urban design tasks involving either land subdivision or the shaping of built blocks.

For those in charge of making urban regulations on pre-existing urban fabrics with a variety of configurations, the present software will permit instantaneous simulations for different cases.

The effect of the urban fabric configuration on the shaping of buildings can be seen as we look deeper at plots 36, 37 and 54. Looking at the graphs on figure 5, it is easy to see that each of the three plots presents its own turning point in respect to the built potential curve and façade area. Another interesting feature is that the relative position of the curves - the functions of the plots - changes or cross each other, according to the variable analysed. For instance, in the first graph the full line representing plot 36 is in between the two other, but in the second graph it is below the two other curves. It is possible that nearly 70 different turning points could appear as the data of all 70 plots were to be plotted. It is possible as well that crossings and changes of relative position would increase in graphs for a higher number of plots. This means that the process of analysis and calculations gets more complex as a great number of different irregular-shaped plots are included.

6 Skyline analysis of 70 plots varying the setback parameters

Finally, simulation on a group of urban blocks were performed. This shows how this model can be used for analysing large urban sections. Here, three distinct scenarios were used, to show how the setback parameter affects the urban built area..In the first scenario, the increased setback for each new added floor, above the third, is m=0.75, in the second m=0.50 and in the third m=0.25m. The rest of parameters remain as before.

Figure 6 shows the urban landscape, in case every plot should reach the maximum constructive potential, based on parameter m=0.50. For comparative purpose, two other alternative urban landscape images, based on other two scenarios, could be generated.

The numbers at table 03 for the three setback rules indicate that the average number of floors may vary from 3.7, 4.6 to 6.2 respectively. This means that the more open and comfortable sky angle is for m=0.75. The best use of land vary in an inverse way- the built area is higher for m=0.25, decreases for m=0.50, and assume the least value for m=0.75

These results show the versatility of this new computational tool, as it can be used not only to model the construction potential, but can also be used by legislators to simulate parameters of setback laws, and see how deeply these may affect the urban landscape.

7 Conclusion: Toward a new process of shaping cities

There is a simultaneous relation between the geometry of plots and urban blocks, in respect to

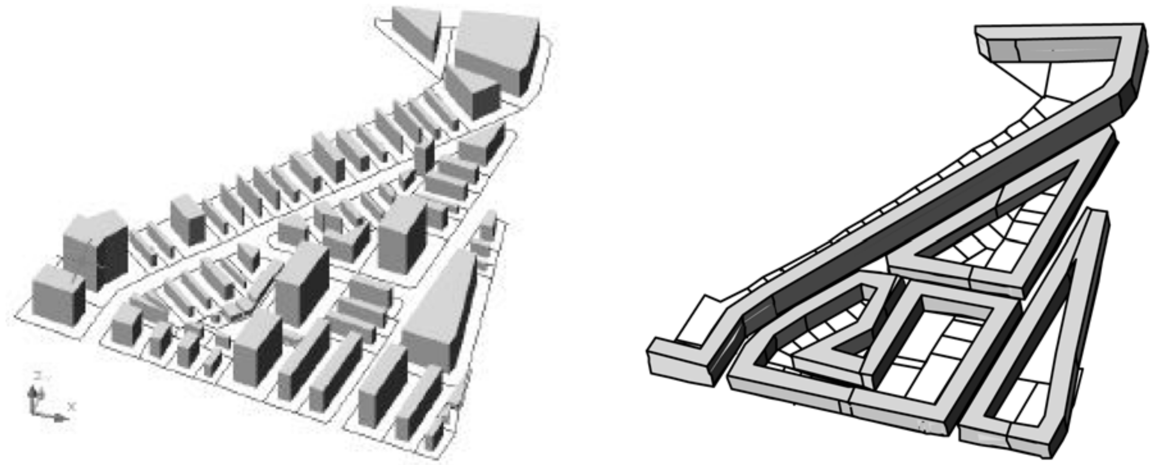


Figure 6. Nuclear and Peripheral Typologies- at the maximum possible built area

Table 3 - Results for setback variation for additional floors as m=0.75, 0.5 and 0.25

	Totals						Average				
M value	No. of plots	Coverage area	Open area	Plot area	Built area	Façade area	No. of floors	Built to open area	Façade to built area	Floor to plot area	Built to plot area
0.75	70	14771	29498	44597	81013	59259	3.7	2.7	0.71	0.33	1.81
0.50	70	12983	29828	44597	90627	69102	4.6	3.0	0.76	0.29	2.03
0.25	70	12427	29163	44597	104238	85397	6.2	3.5	0.81	0.28	2.33

the size and shape, which determines the optimum urban design. Gropius, in 1929, proved this for a notional layout with parallel blocks. Applying new tools, which describe the irregular-shaped urban fabrics, it is possible to simulate and work out the numbers for the actual irregular layouts of the existing towns, cities and mega cities.

Planners must, in their urban design, pursue or seek the equilibrium point that produces, at the same time, the best profitability on the use of land and more open sky angles. Thus, the optimum profitability of the land use and the best sky angles must be the object of successive simulations and search, no matter the typology of the built block in relation to its domain area - whether of central or peripheral occupation. So, the optimisation of an urban design must be achieved as a trade off analysis and a comparative methodology must be exercised.

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