Architectural Morphology and potential use of renewable energy at urban and building scale

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Abstract

The environmental impact generated by the residential sector on energy consumption is estimated at approximately 40%. Architecture and urban planning practice is on the front line directly applying best-case evidence-based solutions to make the most of conserving and generating energy. The excessive and inevitable growth of cities derived in both high and low rise building in most of urban central areas to accomplish social and regular housing demands. Simultaneously, a sustained development of clean energy production technologies and computer simulation allows for an increasingly more accurate prediction of the potential that the architectural morphology possesses on the production of clean energies. High rise buildings bring together: possibilities of high density housing, daylighting access limitations in low floor apartments and issues related with the exploitation of solar irradiation for renewable energy purposes.

Today's powerful building simulation tools can be leveraged for energy modeling during early design phases and even to shape the morphology of tomorrow's cities. For further reductions in building energy consumption, energy simulations done during conceptual design have potential to impact long term energy use both in architecture and urban planning. This paper reviews early conceptual designs of buildings and their interaction with the immediate built environment looking at the consequences in terms of daylight availability and the potential of irradiation use for clean energy generation.

Keywords: Architectural morphology, Residential housing, Simulation, Daylighting, Renewable energy.

1. Introduction

Planning and Building Codes play a decisive role in regulating the development of urban environments. The regulations of urban planning and environmental management of urban land and other rights should guarantee citizens the right to natural light, as a basic human right. (Bautista, G., 2012).

Building simulation is a powerful tool which can be used at all steps of architectural design complementing and fostering innovations in the field of geometry (Gillchcrist, R., 2010) (Mascaró, J.J.; 2010).

Its predictive capabilities have been reflected in many areas of architectural design and energy assessment of buildings and urban environments. (Ajmat, R. 2008).

This paper seeks to explore the potential energy savings and energy production due to solar radiation under different proposed scenarios: buildings as isolated units and buildings within the urban environment.

That is why, knowing how and to what extent buildings' density of the city affects or diminishes the chances of capturing solar radiation, will allow better planning and generate new appropriate policies for better land use.

doi:10.18086/swc.2017.12.01 Available at http://proceedings.ises.org

2. Methodology

Two study cases of the city of San Miguel de Tucuman, in Northwest Argentina are presented. Particular attention is paid to its central area which does not escape the global trend of massive densification often to the detriment of its environmental quality.

For this study both the global environment and the local level of San Miguel de Tucuman were analyzed in the first stage from the legal and morphological point of view.

The starting point of this methodology is the generation of geometries using appropriate software (Autocad and SktechUp) optimized to work modeling morphological and volumetric scenarios; then processing the incidence of radiation on the surfaces (Ecotect or Revit) and finally the post-processing of results with the aid of spreadsheets and graphic interface (Excel) for the presentation of data.

As mentioned previously two different approaches were taken into consideration:

Case A: Building as a unit complying with social housing requirements

Case B: Buildings as part of the urban grid complying with a particular Code of Urban planning

2.1 Case A:

Building as a unit complying with social housing requirements:

The analysis of case A was based in social housing of two different locations. One located in Tucuman (NW Argentina) -Figure1-the other in Berlin (Germany) -Figure 2-:

Case Study A1.: Tucumán (Argentina)

Figure 1 Left: aerial view of the neighborhood- Right: Picture of one block

The case study selected is the COPIAAT II a neighborhood in the south of the city of San Miguel de Tucumán, Argentina, which was built in 1996 by the Provincial Institute of Housing and Urban Development.

It has 14 blocks of 9 flats each. Each block has 3 levels (lower plan plus 2 storeys) with 3 flats per level.

The average energy demand (ED) for each of the blocks was calculated based on the consumption of each appliance with its approximate power (W) and hours of use (h) per day. The annual ED of each flat is 2991.7 kWh / yr. It is observed that the highest energy consumption corresponds to the air conditioning equipment with a demand of 600 kWh/yr. This implies 49,85 kWh/m2 per year of energy consumption. This is a consideration of a mean value for the same type of units; however, it depends on the level of exposure of its surfaces to the environment and to the different U-values one can consider (or a mean U-value). Notwithstanding, the aim of this study is focused in generating a methodology that cooperates in the first stages of architectural design in the analysis of the link between morphology and clean energy generation potential

Values of annual ED:

Energy demand per flat 2991.7 kWh/yr.

Energy demand in communal spaces 522 kWh/yr

Total energy demand per block 27447 kWh/yr

Case Study A.2: Housing Block Altoner Strasse 4-14 - Berlin, Germany

Architect: Oscar Niemeyer

Location: Hansa Viertel, Berlin, Germany

Figure 2 Left: aerial view of the neighborhood- Right: Picture of the block

"In response to Stalin Allee, a street-neighborhood built in East Berlin with a strong ideological load, Hansa Viertel, a neighborhood designed through an international competition, emerged in West Berlin. It is proposed first of all to give an answer to the question of homelessness in Berlin. The answer must be in the area of housing design, but also in the area of construction and use of new materials.

The organization of the competition invites many German and foreign architects to carry out the projects, with the aim of making an international exhibition of architecture, in the style of the Weissenhof. With this approach and the specific problem of housing, Hansa Viertel is a laboratory in which the proposals experience all types: towers, blocks and detached houses with and without patio. The general arrangement is characterized by the rigid orientation of the buildings, both North-South and East-West, in order to obtain good lighting in all rooms. The proposals of linear blocks are of great interest, highlighting the projects of Frizt Jaenecke and Sten Samuelson, Oscar Niemeyer, Egon Eiermann, Pierre Vago and Walter Gropius. (Moya Gonzalez et al, 2015)

For this case, the energy demand was taken from the one stipulated by the Ministry of Environment of Germany

Values of annual ED: (For social housing dwellings considering water heating with electricity)

Flats for 2 inhabitants with heating 2800 kWh / yr per flat. That means 46,66 kWh/m2 and per year

Flats for 3 inhabitants with heating 3900 kWh / yr per flat. That means 43,33 kWh/m2 and per year

Flats for 4 inhabitants with heating 4400 kWh / yr per flat. That means 40,00 kWh/m2 and per year

Energy Estimations

Flats Type B (2) x 12 =   12 flats x 2800 kWh / yr = 33600 kWh / yr

Flats Type C (3) x 54 =   54 flats x 3900 kWh / yr = 210600 kWh / yr

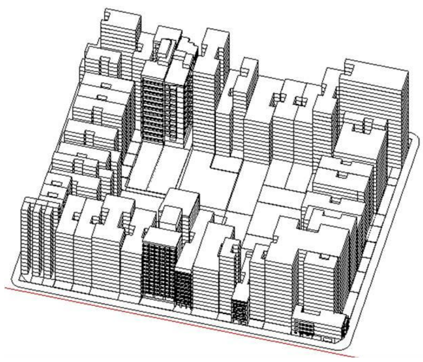
Flats Type D (4) x 12 =   12 flats x 4400 kWh / yr = 52800 kWh / yr

Total energy demand = 297000 kWh / yr

Methodology for Case A

The study of morphological alternatives linked to energy possibilities is the basis for an environmentally responsible and energy efficient architecture. The shape of a building should not be indifferent to the potential for energy production from renewable sources. Recent computer tools allow new ways of conceiving a building from a morphological perspective. In this study the first step consisted in a geometric analysis in order to build the base case geometry in a friendly interface which can interact with different software (Sketch up). Later the Rhinoceros 3D Software together with the Grasshopper Plug-In make it possible to import the building model and work its morphology parametrically, that is to say, using generative algorithms. The main interface for algorithm design in Grasshopper is the node-based editor. The information goes from component to component by means of cables that connect outputs with inputs.

Starting from the traditional block studied, formal alternatives are proposed, maintaining the number of units and surfaces of each one. A systematization of the simulation process has been studied in order to automate the modeling and the process to obtain output data. This methodology can be applied to various case studies of any city. Once representative geometries of each scenario are generated, the potential of solar radiation on top of the roof of buildings is determined using a graph computer model that works on the basis of hourly weather data. The plug-in Insight was used in this case. This methodology allows us to try different geometries for the block during the very first steps of design, analyzing the potential of solar radiation and, consequently, the potential for the production of clean energy. The whole process is described in Figure 3



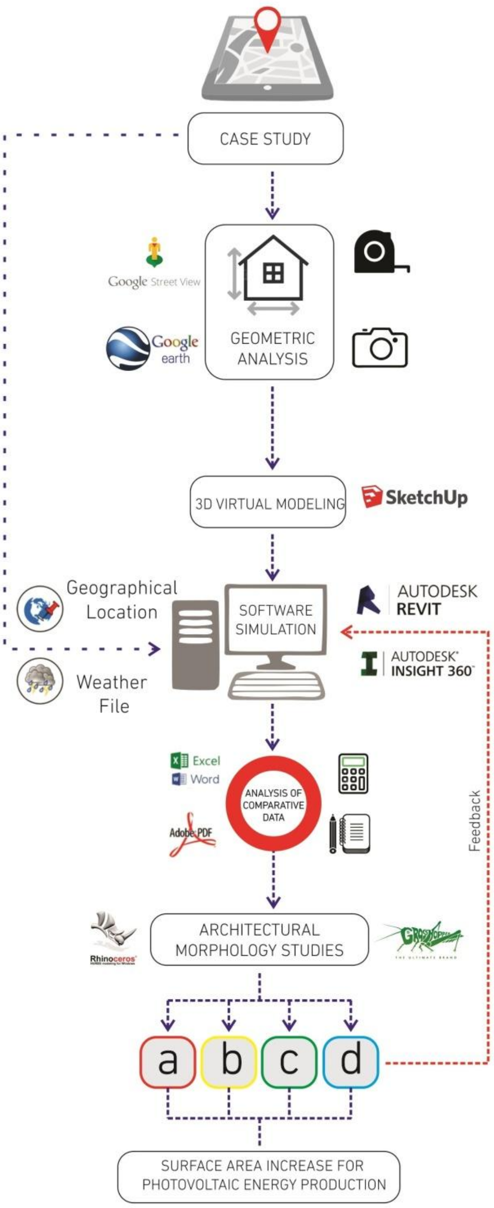


Figure 3 Scheme of the simulation process for case A

Results for Case A

The results of the simulations show the incidence of radiation in different surfaces Figures 4 and 5. However, since the horizontal surfaces are most suitable for the placement of photovoltaic panels, they have been taken as reference in order to make a comparison of the solar-based energy production potential. The alternatives analyzed show the increase of production surfaces that could be obtained from different morphological operations. In that sense, it has been taken as an indicator of the percentage of coverage of the energy demand of the housing complexes under study. Comparatively it can be observed that in the case of Berlin can go over 300% which makes it possible to cover energy demand reaching almost 100%. In the case of Tucumán with smaller scale housing blocks carrying out the same morphological operations only increase up to 65% of the surface. However, due to the potential of irradiation of the climate of Tucumán the possibilities of coverage of the demand are significantly greater reaching 150% coverage of it. In fact the base case has the possibility to cover the excess demand.

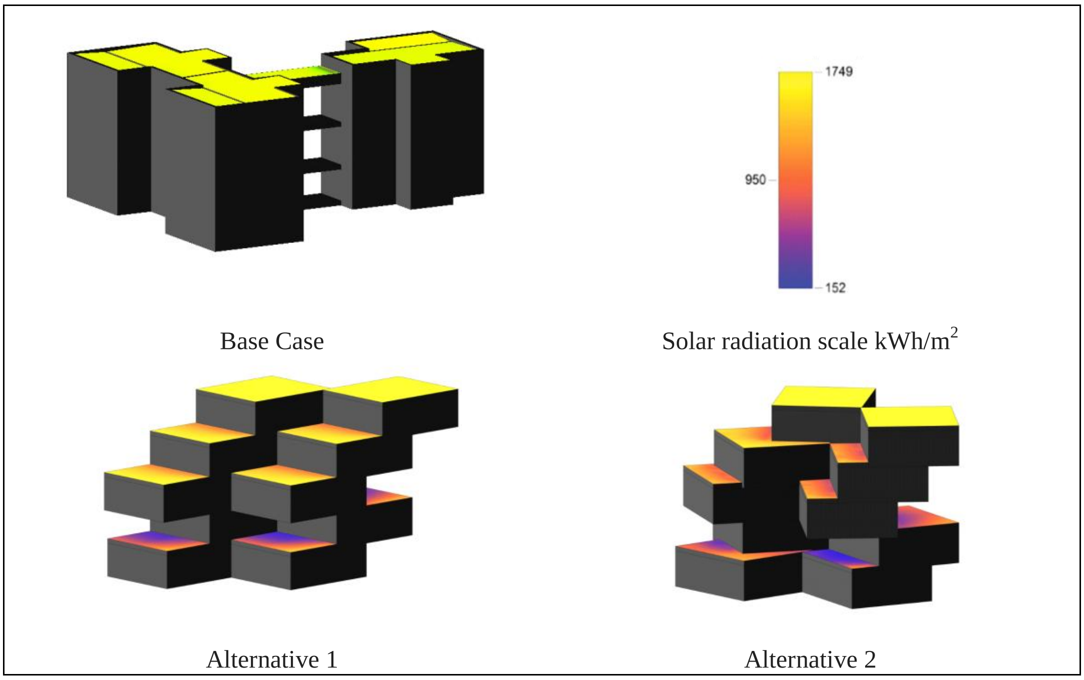


Figure 4: Results of radiation due to morphology exercises for Tucuman-Argentina

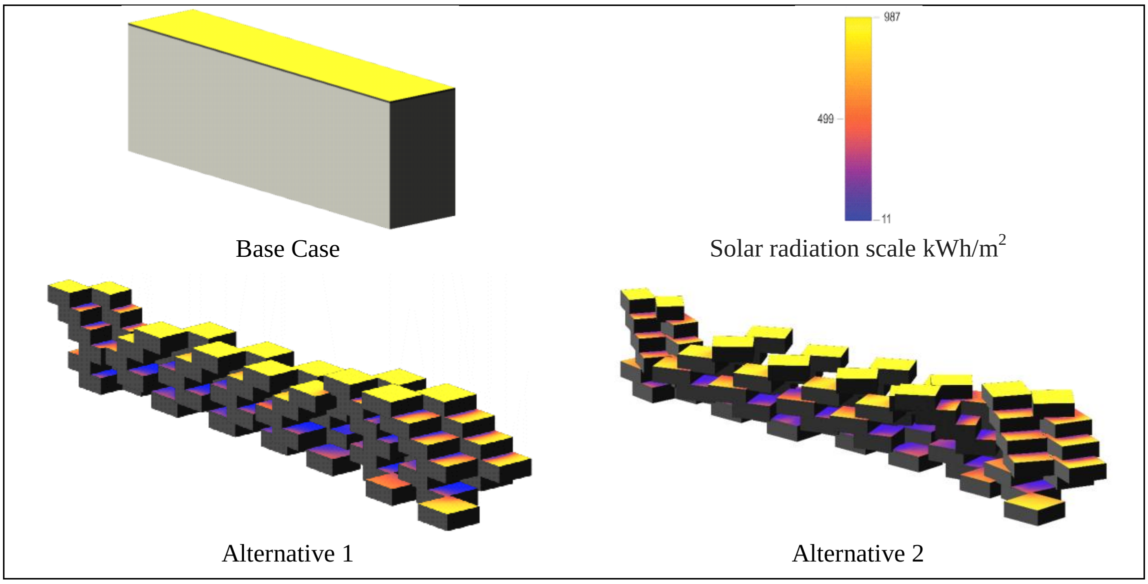


Figure 5: Results of radiation due to morphology exercises for Berlin-Germany

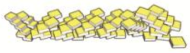
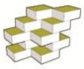
	CASE	SURFACE	CUMULATIVE RADIATION	ENERGY DEMAND	ENERGY PRODUCTION	PERCENTAGE OF ENERGY DEMAND FULFILLED
BERLIN		1080 M2	1,066,432 Kwh	295,900 Kwh	149,234 Kwh	50,50%
		3542,7 M2	1,902,773 Kwh	295,900 Kwh	266,362 Kwh	90,16%
		3782,3 M2	2,084,340 Kwh	295,900 Kwh	291,666 Kwh	98,64%
TUCUMAN		179,4 M2	310,309 Kwh	27,447 Kwh	43,328 Kwh	158%
		295,9 M2	353,764 Kwh	27,447 Kwh	49,520 Kwh	181%
		240,5 M2	288,544 Kwh	27,447 Kwh	40,488 Kwh	148%

Figure 6: Summary of annualized radiation due to morphology exercises for both locations.

2.2 Case B:

Buildings as part of the urban grid complying with a particular Code of Urban planning

This exercise aims to explore the potential of energy savings and the production of energy from solar radiation with the application of the current Code of Urban Planning of Tucumán under different scenarios proposed. Solar energy plays an important role in replacing fossil fuels to generate electricity without emitting pollutants and without the need for fuel. (Li, 2014).

For this study the current environmental legislation was analyzed in the first stage in order to know how and to what extent the density of construction of the city affects or diminishes the possibilities of capturing the solar radiation, as well as the generation of new appropriate policies for a better use of the land. For example, we consider the morphology of a solar facade as a building component that is feasible to generate energy and allows the entry of daylight into the interior spaces, a key aspect of the design of such facades is the determination of total energy benefits. (Li & Lam, 2008).

This work has a previous data base generated and processed to be able to obtain the different scenarios proposed (Ajmat et al, 2011). The sector to work is selected, the morphological proposals are generated and the simulation of surface radiation is carried out. The starting point of this methodology is the generation of appropriate software geometries; then processing the incidence of radiation on surfaces and finally post-processing the results with the help of spreadsheets and graphical interface for data presentation. (Hui,2001) (Mesa et al,2010)

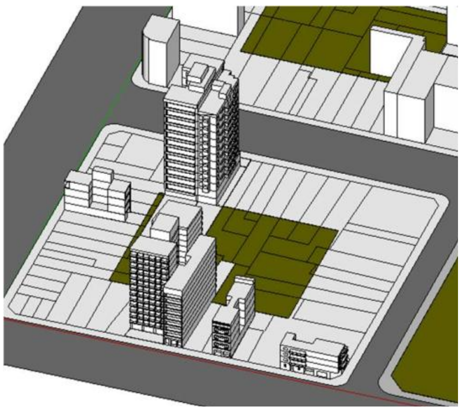



Figure 7: Left: Aerial view of urban sector for simulations - Right: Sketch up model to be exported for calculations.

Methodology for Case B

The proposed Simulation Process (Figure 7) is based on a sequence of data that can be modified at different points, leading to the obtention of data from different scenarios or typologies simultaneously. It analyzes in a first step the basic information of the grid of the city, this information is checked against what the Urban Planning Code proposes for each sector of the city and through a processing of it with different software. It can provide a number of scenarios necessary to carry out studies of the morphology of the city or a selected city sector. Once the necessary information is obtained for each scenario, it is modeled in both 2D and 3D (at this point there is a Loop regarding modifications that can be made on the information data base of the model that result in automatic changes on the 3D morphology of it). Finally the analysis with the calculation of solar radiation and shadows of the 3D model is performed using the appropriate climate file and its geographic location. Once the results are obtained we can review the initial model and make modifications to obtain different morphological alternatives for the same scenario and thus compare different performances.

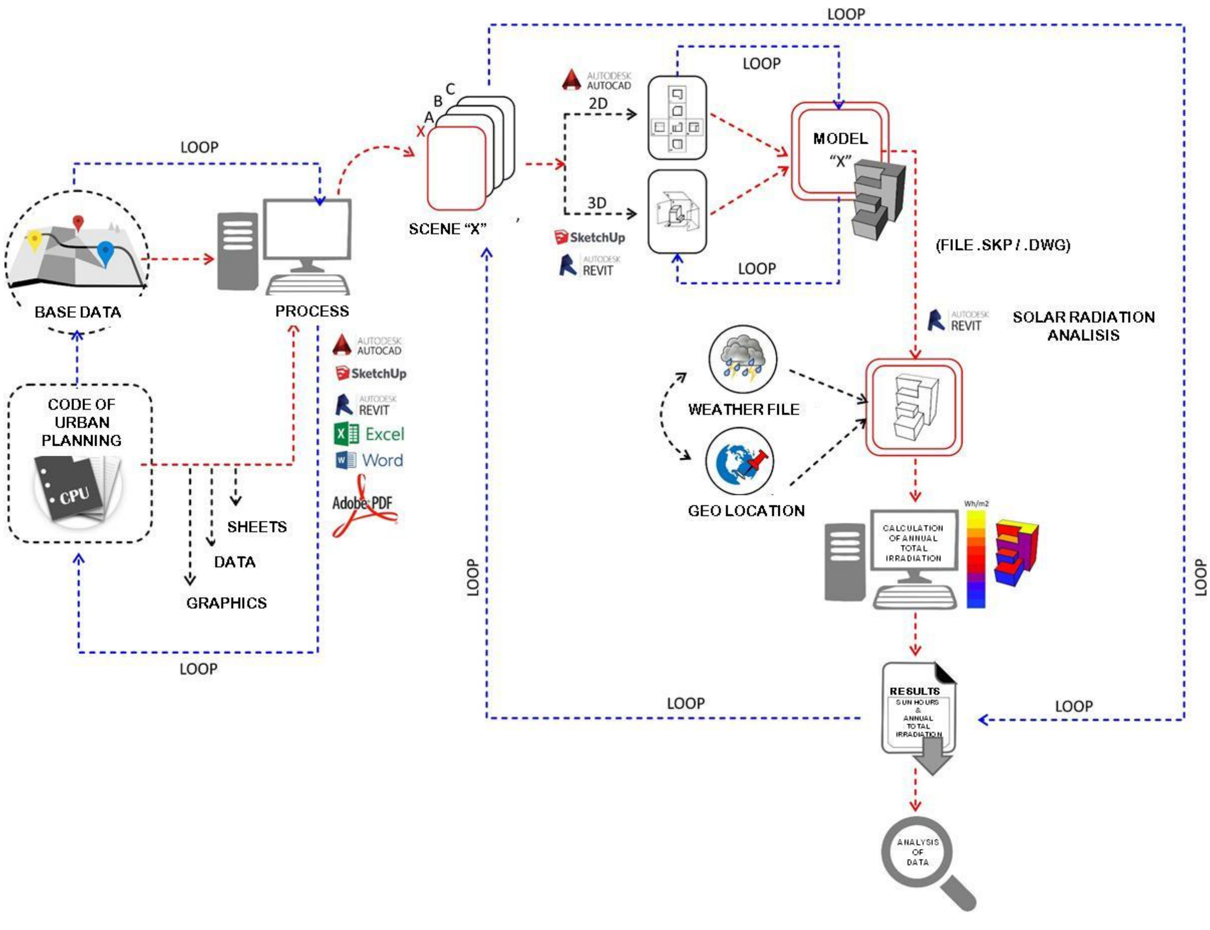


Figure 8 Scheme of the simulation process for case B

Two scenarios were simulated in order to analyze the potential and limitations of the urban densification process: Maximum built surface until the lateral limits and therefore a certain height can be reached. This was identified as: Scene 1. Minimum built surface with maximum height. This was identified as: Scene 2.

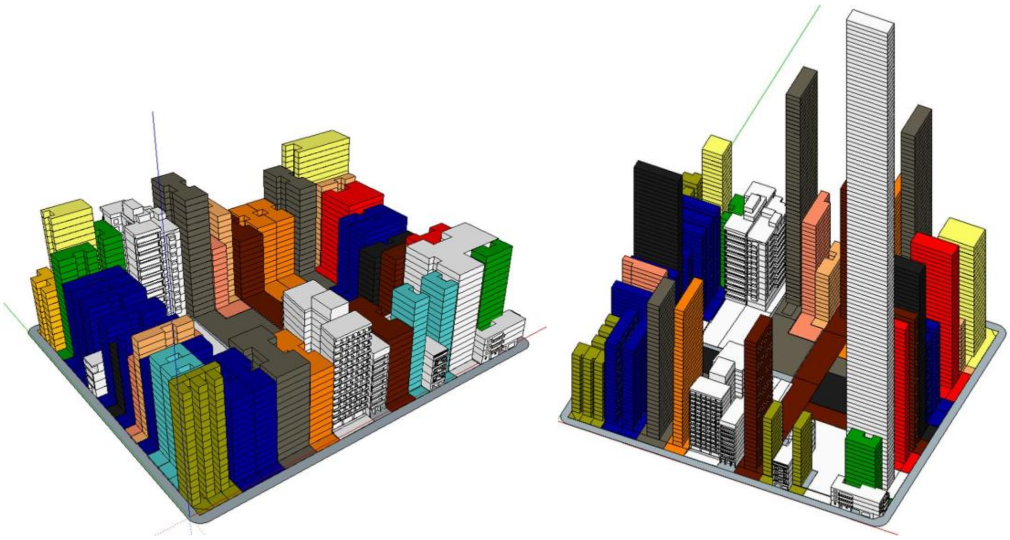


Figure 8 Left: Scene 1 Maximum area constructed minimum height-Right: Minimum area constructed maximum height

Results for Case B

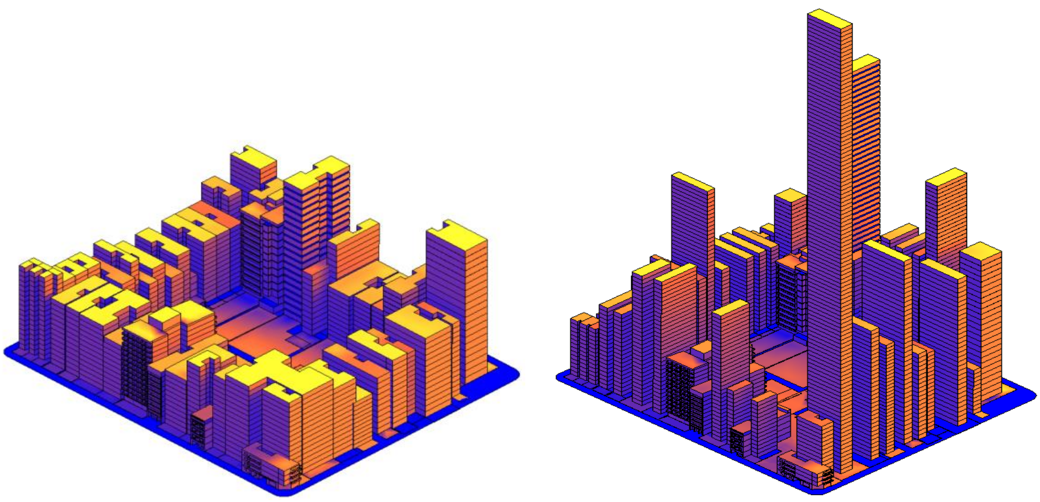


Figure 9 Left: Results of Solar Radiation for Scene 1 Right: Results of Solar Radiation for Scene 2

Based on this modeling, geographic and climate data are loaded. Then it proceed to the calculation of irradiation. As for the area in square meters considered for both cases we observe that Scene 2 is a 14% greater in surface than Scene1. This consideration is made since a greater surface can accumulate a higher radiation amount, however the obstructions due to the morphology of the buildings must be considered too. When analyzing the results Scene 2 exceeds Scene 1 by 6%with respect to amount of accumulated solar radiation per square meters. We can say from these comparisons that for the cases studied Scene 2 exceeds Scene 1 by 19% with respect to its total annual irradiation capacity from the point of view of morphology (Table 1).

Table1: Results comparison between scenarios

	Scene 1: Minimum Height	Scene 2: Maximum Height	Differences %
Total study surface area [m^2]	506116.57	587776.40	13.89
Study average insolation value [kWh/ m^2]	224.34	238.53	5.95
Total study insolation value [kWh/yr]	113541961.94	140201310.76	19.02

3. Discussion

Case A

The influence of the morphological dispositions can be observed in the first place in the possibilities of extension of the surfaces exposed to the radiation. It is also observed that the type of morphological arrangement, even if it enlarges the surface, can generate shadows thrown between parts of the same building when moving from a compact to a more disaggregated shape. In any case there are direct consequences on the potential of solar energy exploitation. Terrestrial coordinates and the local climate characteristics also influence the availability of the solar resource. It is for this reason that the role of the designer of architectural form must be appropriately combined with local site and local climate considerations. Since we have limited ourselves here to the analysis of the horizontal surface, the behavior of the other surfaces of the architectural form are still to be experimented in order to develop the shape of future buildings..

Case B

It is evident that both the shape and height of each building and the ordering between plots influence the capacity of a city to make the most of solar energy. Urban building codes fulfill a very specific role; the future possiblities of production of clean energy will comply with it and consequently the reduction of carbon dioxide emissions (De Schiller, 2002). In Case B two extreme scenarios of application of the building code of San Miguel de Tucumán were studied. The study of the minimum height scenario is perhaps the most feasible due to the technological possibilities, since the case of maximum height does not seem to be possible execution in all the plots. However, using the minimum and maximum values allowed by the Urban Planning Code of San Miguel de Tucumán, make it possible to question this code, since when generating the scenarios, the morphology of the resulting set of buildings does not seem to come from a basis of criteria, norms and guidelines to be taken into account to improve habitability and solar conditions, but, to restrict densification, raising the problem of land use from the real estate point of view. Thus, the possibilities offered by the technology and the characteristics of the ground where these buildings are located, and not the regulations provided by codes and ordinances, which actually limit urban growth, which give rise to the urban morphology resulting from the city. But the methodology which has been produced would allow simulating an unlimited number of combinations and probabilities with a costless time investment. This would allow us to experiment with new regulations within the code or to test the possibilities of collecting solar energy from a new building to be built in a given context.

4. Conclusions

A methodology of evaluation of the architectural and urban morphology in relation to the potential use of renewable energy has been presented. It is valuable at the scale of building and city in order to assess the influence that the form has on the availability of surface for the capture of solar energy. In both cases - building and city - morphological operations allow designers to increase the possibility of a greater and better use of solar energy whether this is by surface increase or by the study of the shadows that buildings throw each other (Kamal & Smiriti, 2014). From the results obtained we can verify the importance of urban morphology and therefore the influence of city planning codes in terms of the availability of natural light and the potential use of irradiation for energy generation.

This approach arises from the search for strategic solutions, given the need to create conditions of habitability in areas of high density population as well as in the interior and exterior of buildings; which today seems to lack effective solutions. Therefore, a simplified process that facilitates consideration of the morphology and size of future constructions is a valuable goal sought by designers. The possibilities offered by simulation as a prediction tool are significant; energy simulations carried out during the initial stages of design have the potential to impact on long-term energy consumption. On the other hand, we are challenged as architects of the cities of the coming century challenging formal innovation and creativity in relation to the interaction between buildings.

A systematic simulation process to analyze the consequences of densification, an output of the current building trends, applying a methodology to investigate the real effects of the implementation of the urban planning codes enable.

- The analysis of the production potential of clean energy.

- Pre visualization and study of the habitability of particular situations (courtyards within high-rise buildings).

- To propose new legislation that addresses problems of habitability and sustainability.

-To challenge the established morphological paradigms of low and high rise buildings.

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6. Acknowledgements

The authors would like to thank: the National Agency for the promotion of science and technology, the National Research Council and the University of Tucuman, Argentina for their continuous encouragement and financial support given for this research work.