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Article

A Critical Assessment and Projection of Urban Vertical Growth in Antofagasta, Chile

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Abstract: Vertical cities' growth is argument of discussion worldwide. Population increases and a better soil use are needed, in terms of efficiency and density, in many cities of the world. However, an excessive vertical growth seems to be harmful, especially near the green areas of midtowns. In this paper, the case of Antofagasta is studied. The paper studies different possible future evolutions searching for a bearable development, respecting the society needs and the environment. Parameters analyzed are: temperature, humidity, solar radiation, wind speed and direction in the studied area. Results show the impact of building growth in terms of overheating and wind reduction on the ground area studied. Additionally, the social impact of living in towers is also discussed in the paper, searching for better design in order to guarantee user's comfort, satisfaction and stimulation in their residences. Thermal, visual and acoustical effects produced by towers are considered in the critical evaluation of the Antofagasta city evolution. Part of this work relates to architectural workshop "energy and architecture" conducted by the authors at the School of Architecture of the Catholic University of the North (UCN) in 2012.

Keywords: vertical growth; green areas; urban sustainability

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1. Introduction

Vertical growth of cities is an argument of interest from an academic and professional urban design point of view, worldwide, because of the impact of cities on the definition and understanding of "sustainable life". In last years, many scientists and technologists focused on urban growth, urban sprawl, entropy generation of the cities, scaling laws and others issues in relationship with the concepts of density and organization [1–5]. However, research conducted is not always communicated well to the entire society. A very common idea, for example, is that vertical growth is desired to reduce the sprawl, increase organization and distribute the energy and matter resources better. Slender towers are used as a symbol of development, richness, efficiency; especially in the developing countries, where cities' transformation was a fragmented process from ancient structure to modern requirements and the election seems to be between villages (no services, no communications, no richness in general) and modern vertical cities, with iconic skylines, international airports, people arriving and leaving continuously, *etc*.

In a recent interview, Bettencurt and West [6] refer for example to a "superlinear" regulation of the city living: "We broke away from the equations of biology, all of which are sublinear. Every other creature gets slower as it gets bigger. That's why the elephant plods along. But in cities, the opposite happens. As cities get bigger, everything starts accelerating. There is no equivalent for this in nature. It would be like finding an elephant that's proportionally faster than a mouse." Bettencourt and West, studying cities like self-regulating systems, opine that city density responds to a "maximum entropy" criterion of evolution: the better the organization, the higher the number of users of the system. Under this point of view, they said that an individual life is quite less expensive in the "natural" state, than in the city, were needs are generating needs and energy demand increases such as entropy does. This vision seems to consider the same sprawl as a positive sign for cities and in general to believe that complexity needs expansion and energy consumption increase.

The issue of whether vertical growth increases consumption of energy and matter, with respect to horizontal sprawl, is not the main argument of this work. However, it has to be said that both strategies increase the size of the city in terms of people living in there. The price for this increase is the modification of the environment that is the focus of this research. Building construction affects the neighborhood in terms of change in ambient parameters that can be measured or simulated. These changes in the operative parameters (used for example to define comfort standards inside and outside of buildings) are the main interest of this work. Authors from different disciplines are now studying the cities' transformation and the planning related issues (see for example the cited works [1–5] and other researches of Coch *et al*. [7], Bettencourt and West [8], Wheeler [9], Robinson [10]).

It will be interesting to search for which kind of monitored or simulated results can be helpful at the time of defining the city entropy production, the effective energy transformations, the parameters for new design strategies in urban design and studies.

This article contributes to the open discussions and research about sustainability in urban environment, and it was projected as an open article, trying to put together different disciplines and efforts: at least the architecture students, managing design concepts and using observation as the principal manner to resolve problems; and engineer more scientific point of view, searching for laws (or experimental evidences) in order to explain what is happening and why.

2. Case Study

The town of Antofagasta is located in the north desert coast of Chile, in a typical arid climate, latitude 23° south and longitude 70° west. Green areas are quite precious in arid climates, and have to be protected from the building overheating effect, as noticed for example by Hatuka and Saaroni [11]. Arid climates, for instance, need more attention when designing the radiant scenario, because of the impact of the mean radiant temperature on the outdoor thermal comfort and on the same plants' growth. In the last 20 years almost 30 new tall buildings have been constructed in Antofagasta, which are more than 70 meters high. At least 7 of these new buildings are currently negatively affecting the "Avenida Brasil" area, a green park of 70 meters area and one kilometer long, which is the principal green area of the city center. Antofagasta city is located in the Atacama Desert close to the Pacific Ocean. The climate is typical of desert coast, with high radiation levels, no precipitation and average temperatures between 15 and 25 °C during the whole year [12].

In the city center the green park of Avenida Brasil is one of the icons of Antofagasta. Figure 1 shows the park form, S-N oriented, surrounded by the city, but quite close to the sea. Building growth near this site has been uncontrolled during recent years. Of the ancient Antofagasta buildings only few houses are used nowadays. These traditional houses have two floors with a total hight of about 8 meters. Especially during the last 20 years, more than 30 towers have been constructed in the city center and others are under construction (Figure 2). The economical growth of Antafagasta signified an important population growth and the center area has been transformed in order to attend the new needs of the residents. The city has a population of about 250,000 people, but it is expected to rise in the following years. An important part of this population is represented by commuters, that work in the mines and consider Antofagasta just as a temporary place to stay. Most of new construction are sold out to firms or inversors. Under these conditions, it appears quite "natural" that first proposal is the construction of tall buildings. Tall buildings are considered to be less expensive and to optimize land use. However, uncontrolled built area improvement could be counterproductive for the sustainability of the site, especially considering the low presence of vegetation in the city. Avenida Brasil is an area with delicate relations between houses, plants, sky and sea. Modifying the environment could cause, for example, an excessive increase in the shadow zone, or a wind deviation from natural movement.

Figure 1. Antofagasta midtown sector with green area of Avenida Brasil and prevailing winds.

Figure 2. New residential building construction in the "Avenida Brasil".

Local School of Architecture, always sensitive to the city's problems and solutions, is actually less involved in the planning than previously. Nevertheless, our perception is that the city is submitted to morphology changes that do not consider associated problems of transportation, green area, pedestrian, children areas, services, *etc*…. The main reason of the city's growth is the facility to offer dwellings and offices to people that have reached a new life status. Life style is consecuently transforming to an automobile and elevator-dependent life, organized inside of buildings. For this reason, in the School of Architecture of the local University, UCN, we focused a workshop to understand the possible future scenarios of the city and started investigations using different simulation tools to obtain some microclimatic data of different areas potentially affected.

In addition, professors are starting research on ambient parameters that could be considered in sustainability evaluations of urban growth. In this paper we present Ecotect [13] and Envimet [14] preliminary simulation results of solar incoming radiation, temperatures and wind deviation in the Avenida Brasil area, under proposed scenarios of actual trend and bearable development. This sector was selected because of its importance in the future city development: new construction is concentrated in this sector, which is the most expensive and it is supposed to be the place with the better quality of life of Antofagasta. It is also the only relevant green area of the city center.

3. Methodology

3.1. Architecture Workshop

In the workshop, students were asked to respond to the question of the urban habitability analyzing the following factors:

- Urban light, acoustic and climatic environment;
- Building needs in terms of operability, services, public and private zones;
- Integration of energy and comfort concepts.

Workshop results shows that current construction is not responding to required parameters, especially environmental factors are ignored in Antofagasta urban development. The main factor (or the only one in most cases) taken in to account is the usefulness of a site—thus, how to put more people in fewer square meters. Student opinion with respect to this fact is obviously that a new paradigm of architecture is needed in order to reach a sustainable city, with green areas, sun exposition studied in the first design stages, acoustic integration in natural environment and limitation of urban noise, climatic approach in orientation and internal distribution design of buildings, *etc.*

3.2. Defining "Urban Sustainability"

In respect to simulations studies, the two situations considered were the actual trend future projection and a "sustainable" or at least "bearable" development. Considering a traditional definition of "sustainability", coming from Brundtland Commission [15] and successive development of the concepts, it seems that economic distribution is far from contributing to an equitable society in Chile today, and this inclination will probably still exist in the future 50 years. If a plain "sustainable" projection of Antofagasta is quite illusory, a bearable future is possible to obtain if environmental and social aspects are considered in urban planning. For instance, to decide what constitutes a bearable development is a difficult task, with quite arbitrary definitions and suggestions. In Antofagasta, there is a currently on-going project called "Creo" [16], which is searching for an acceptable definition of sustainability for the city. Institutions and private clusters are working on this plan; however, presented results have been (as yet) quite poor from an academic point of view. In this paper we consider that a bearable urban planning has at least:

- to consider 30% of soil use as green area;
- to permit a maximum of 6 floors (maximum high without elevators) of residential blocks;
- to plan the orientation of blocks to use better the wind (heat evacuation);
- to stop patrimonial houses demolition.

These considerations come from different references and from direct observation of Antofagasta city. For example, some master plans of arid cities suggest avoiding tall buildings (nevertheless, some authors [17] disagree). Visual lines in front of the coast are also an important limitation in vertical growth, an issue that has been almost completely ignored in the last 30 years of development of the city.

3.3. Simulation Studies and Experiment

Software used in simulation are Ecotect, developed by A. Marsh and the Square One research group and actually commercialized by Autodesk, and Envi-met, developed by M. Bruse. Ecotect is a building simulator that can be used to represent some urban issues like shadowing and ventilation; Envi-met is a dedicated environment simulator, which obtains weather modifications due to buildings, soils, vegetation in considered area. Envi-met is used to analyze exterior spaces, pederasties comfort, and urban impact on environment in general [18,19]. Future predictions were done considering actual trend or a change in terms of sustainable use of green areas and reasonable building high. A new trend is characterized by sustainable design of new construction, permitting a maximum of six floors and incorporating green area and natural ventilation concepts. As simulations are not always conclusive, we also realize a physical model of the zone and test it in a water-table to qualitatively understand the ventilation concepts. The experiment confirms the general distribution of air velocities for the actual morphology. Figure 3 shows the model. Experiment took place in the Laboratory of Comfort of the Architecture Department, Federal University of Santa Catarina, Brazil in february 2013.

Figure 3. Physical model used for the experiment.

The most important results of the experiment are to show the transversal flows that could to be blocked by dense construction in the east side of the street. The city sector behind the street needs the air flow to guarantee heat evacuation and air change possibility using natural ventilation design strategies.

4. Results and Discussion

Simulation results are presented in the following order:

- Shadows and solar exposition;
- Temperature and humidity;
- Wind protection and natural ventilation.

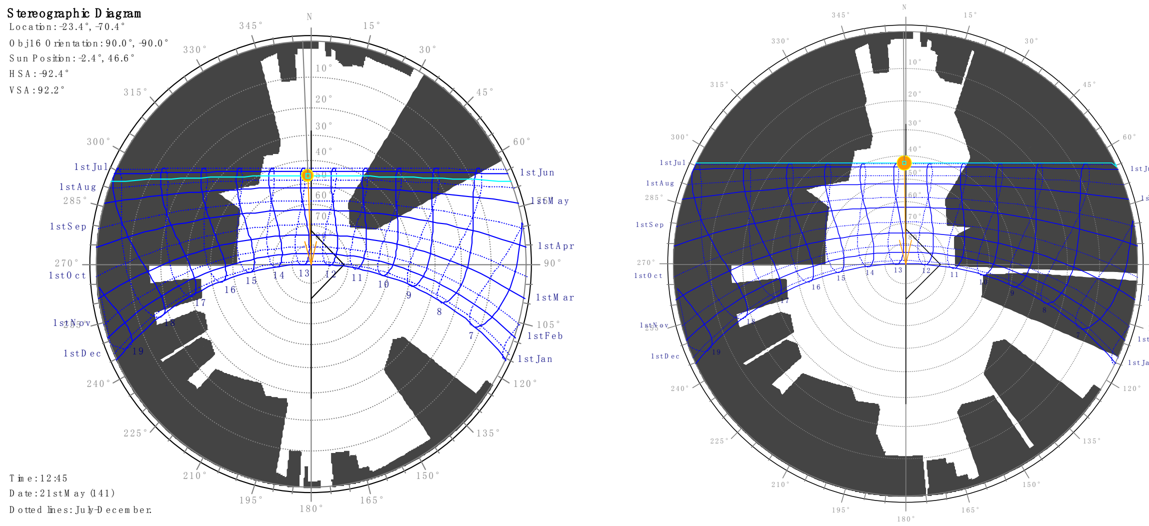
These aspects quite exhaustively explain the comfort in external spaces using the PMV concept [20], which depends on four ambient variables: temperature, relative humidity, mean radiant temperature and air velocity. However, it has to be noted that PMV depends on other aspects, like metabolism and clothes. Moreover, the PMV concept is more effective in internal comfort evaluations. It has been shown that people are more tolerant to weather parameters variation than predicted, especially outside. This fact depends on people's expectations, which are lower outside than inside of buildings [21].

4.1. Shadows and Solar Exposition

With respect to shadows, the park area of Avenida Brasil is today partially obstructed on the west, but it is exposed to the sun on the north. This fact signifies a relative usefulness of the green area during the morning, and a general user dissatisfaction during the afternoon, when wind and shadows combine. During the summer, with high solar radiation and Sun to the zenith, green area is too much exposed and people prefer to stay in the protected zones near the buildings.

The actual trend of construction can generate shadows in the east side of the park, and it will be dangerous because the morning sun is desired by users and seems to be one of the actual values of the park. The park area is divided in 8 parts in the Ecotect model. Figure 4 shows the sun-path diagrams for the 4th part (in the center) in the actual situation and in the future following the actual trend in construction. It can be observed that shadows are desired in hot dry climates; however, it has to be noted that there is an enormous difference between plant shadowing and building shadowing, as expressed for example by Rogora and Dessí [22]. Plants have superficial temperatures comparable with air temperatures, whilst buildings can have temperatures up to 10 degrees higher. For this reason mean radiant temperature produced in a building-protected street can be higher than an exposed one.

Figure 4. Shadow range for actual and uncontrolled future situation in the park center.



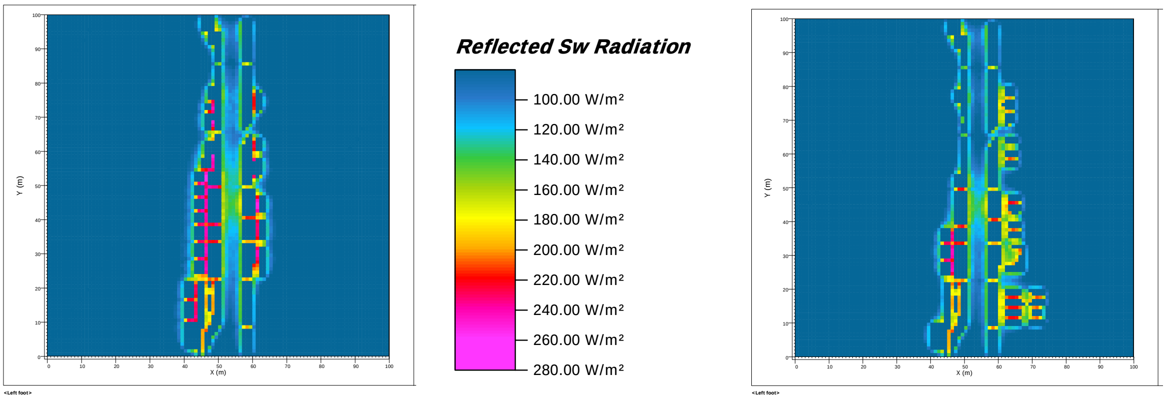
Moreover, sky obstruction is considered as one of the principal causes of "heat island effect": buildings are reducing the soil albedo and also night re-irradiation of long wave is partially neglected. This zone of the world has high values of sky clearness, so night re-irradiation reduction can be positive effects in order to decrease the thermal oscillation; however, the heat island effect is dangerous even in a city like Antofagasta. City growth will have unpredictable effects on this overheating, it appears very important to understand the possible evolutions and establish now the possible actions to take.

Figure 5 shows the reflected solar radiation that directly affects the central area. Whilst direct radiation is almost the same (about 1400 W/m^2 in the summer at 12), reflected radiation seems to be 20–40 W/m^2 higher in an actual trend scenario. The effect of this reflected radiation and of the re-emitted radiation is an increase of the mean radiant temperature. This increase is difficult to quantify exactly, due to its variability during the day, but preliminary studies suggest mean radiant temperatures of 1–2 °C higher in a tall environment than in a relatively low buildings scenario.

4.2. Temperature and Humidity

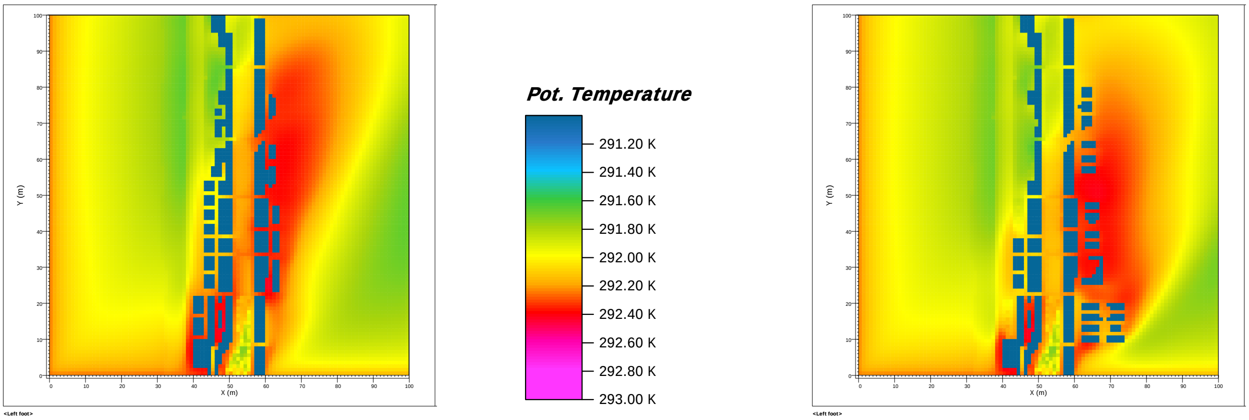
Figures 6 and 7 expose the ambient and the mean radiant temperature distribution for summer solstice in both urban growth cases. Radiant temperature depends strongly by the surface properties. On a summer day, asphalt road has an average temperature of more than 30 °C and the green area almost 22 °C.

Figure 5. Reflected solar radiation on the green area in future scenarios, summer, 15 h.



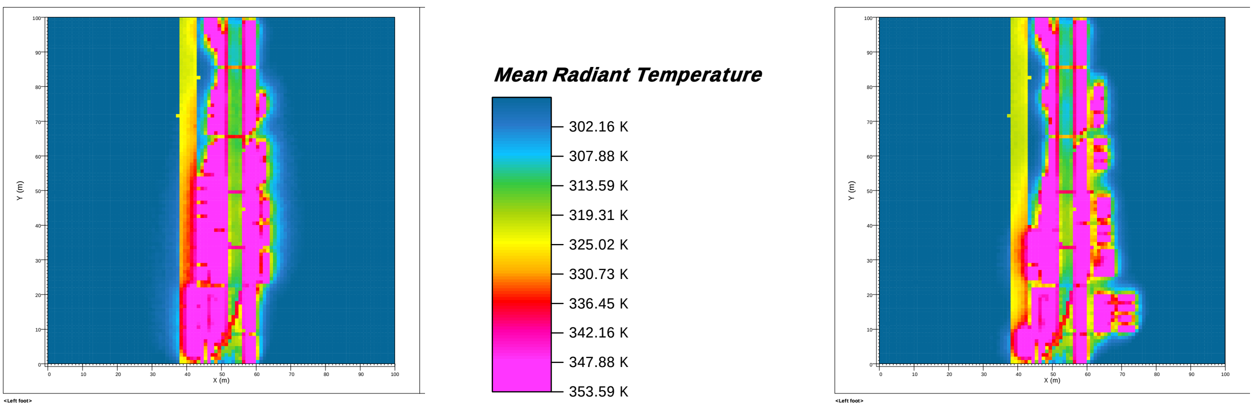
(actual trend) **(bearable)**

Figure 6. Envi-met ambient temperature for future scenarios, summer day, 12 h.



(actual trend) **(bearable)**

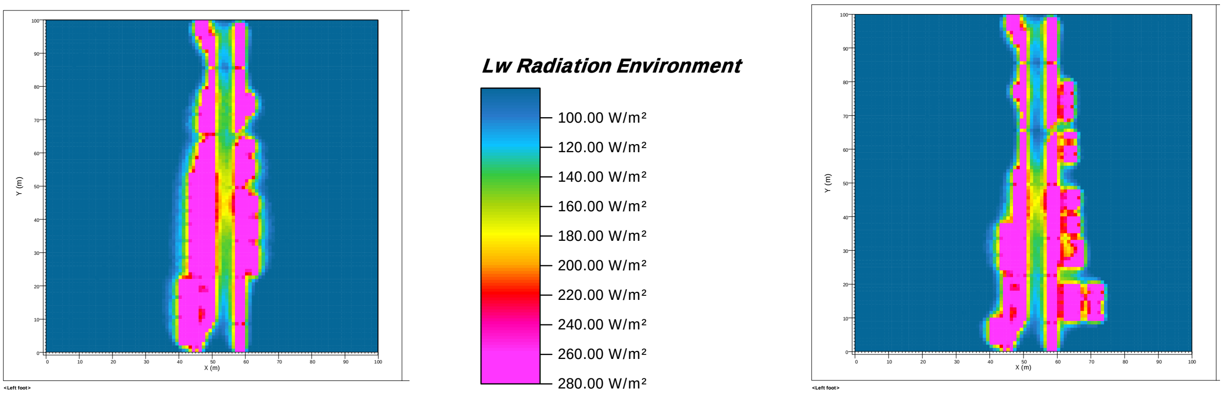
Figure 7. Envi-met mean radiant temperature for future scenarios, summer day, 12 h.



(actual trend) **(bearable)**

Results of more extensive simulations [23–25] show that uncontrolled development could cause an increase of about 0.5 °C in ambient temperature and up to 2 °C in mean radiant temperature, depending on the hours of exposition. In particular, the afternoon period is quite sensitive to different urban morphology near the site considered. Figure 8 shows the low radiation scenario at 15 h on a summer's day. It can be observed that central area has values of 30–50 W/m^2 higher in actual trend than in bearable development. Buildings are generating shadows, but at the same time are increasing low-wave radiation environment during the day. With respect to humidity, two analyzed scenarios do not have substantial differences: relative humidity is close to 90% in the first line from the Ocean, but decays very fast moving towards the city. In arid climates, thermal comfort is determined by other parameters, like the radiant environment and ventilation.

Figure 8. Envi-met low radiation environment in future situations, summer day, 15 h.

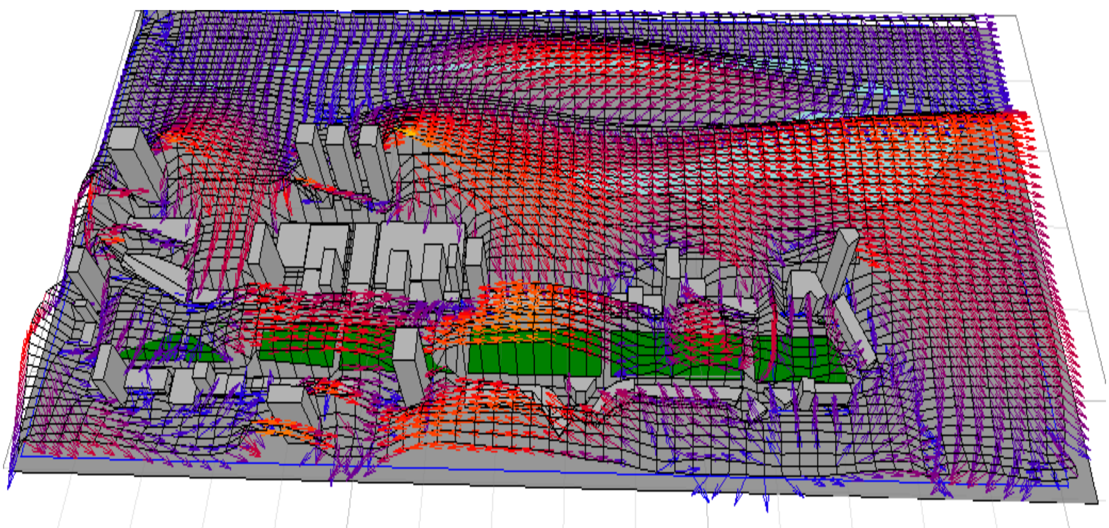


(**actual trend**) (**bearable**)

4.3. Air Flows

One of the most important effects of the new construction will be wind desviation from the actual situation. At the moment, air is flowing from the ocean (south-east) and is entering in the park from south and leaving it in the north. Figure 9 shows the actual air flows simulation obtained with Ecotect. Simulation result was confirmed by experiment conducted in the water-table. Sustainable construction have to consider the overheating effect caused by the sun radiation in this location, and ventilate appropriately the facades and the roofs. The figure shows air flows in the area, with controlled transversal flows in the new built areas.

Figure 9. Simulation results for actual situation.



The situation gets complicated in the case of following the actual trend without sustainable considerations. In the north part of the area, wind generates turbulences and air velocity is increased by some tunnel effects. The east part of the area presents buildings that can not be correctly ventilated. Figures 10 and 11 show details of the natural ventilation strategy in the east side of the park area. New constructions have been designed considering a maximum six floors of vertical growth and orientation S-N of the principal fachades. Green areas are alternatively inserted between residential blocks. The results is a good ventilation, controlled and used to evacuate overheating in summer.

Figure 10. Natural ventilation strategy in bearable development of the area.

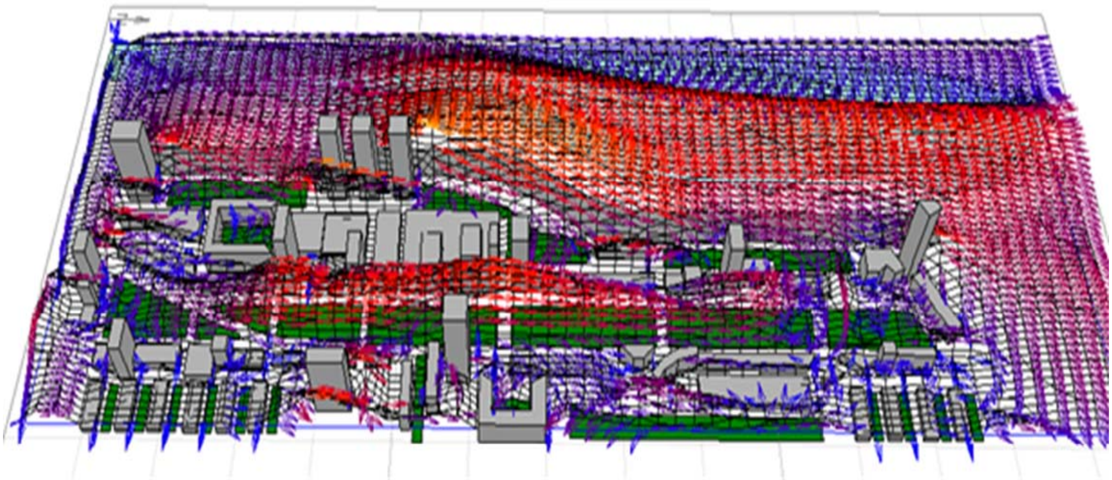
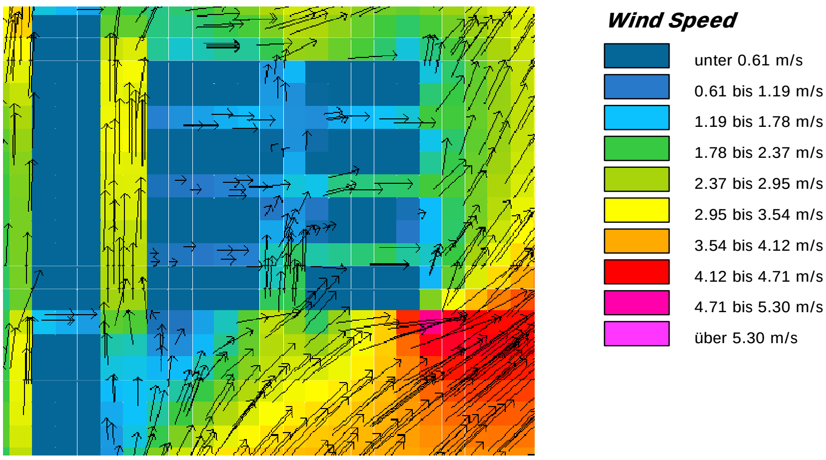


Figure 11. Wind use in sustainable development of the area (Envi-met color code).



Proposal morphology helps SW wind to enter in the streets and ventilate the building's fachades and roofs. S-N ventilation in the central area transforms into transversal ventilation E-O in the adjacent area. Construction of taller barrers on the East side of the street could limit the wind use for all the right area of the city.

Wind in Antofagasta is an important resource. It comes from the SW with a speed of almost 15 km/h. This condition makes it useful to ventilate the city, if the morphology does not change the situation, for example, generating the barrer mentioned above and reducing the tranversal air flows. A deep canyoning effect has also to be avoided, in order to not exceed the air speed of the situation exposed in

Figure 11, where 0.6 to 1.2 m/s are usefull velocities to cool the neighboor and can be also used to cross ventilate the buildings. Table 1 resumes the environmental parameters evolution during a summer day for the consideded situations and PMV resulting values for users standing in the central point of the green area.

Table 1. Ambiental parameters and comfort evaluation, summer day, center of the street for actual proyection (A) and bearable development (B).

H	Met	Clo	T (°C)		RH (%)		V (m/s)		MRT (°C)		PMV		PPD	
			A	B	A	B	A	B	A	B	A	B	A	B
8	1.5	1.5	13.9	14.0	60	60	2.2	2.1	10.9	10.7	−0.8	−0.8	18.5	18.5
9	1.5	1.5	19.3	19.1	53	54	1.3	1.4	18.0	17.0	0.2	0.1	5.8	5.2
10	1.5	1.5	19.9	19.8	51	52	1.5	1.6	19.9	19.9	0.3	0.2	6.9	5.8
11	1.5	1.5	21.0	20.9	47	48	1.3	1.3	27	26.8	0.7	0.6	15.3	12.5
12	1	1	22.4	22.2	44	45	1.3	1.4	52.1	51.0	1.4	1.2	45.5	35.2
13	1	1	23.6	23.5	41	42	1.4	1.4	47.3	46.5	1.1	1	30.5	26.1
14	1	1	24.6	24.6	38	39	1.5	1.6	45.0	45.0	1.2	1.1	35.2	30.1
15	1	1	25.2	25.0	33	31	1.5	1.5	34.0	32.5	0.4	0.2	8.3	5.8
16	1.5	1.5	19.4	19.2	49	47	1.3	1.4	10.3	9.8	−0.1	−0.1	5.2	5.2
17	1.5	1.5	19.3	19.1	53	53	1.2	1.2	9.7	9.6	−0.1	−0.1	5.2	5.2
18	1.5	1.5	19.2	19.0	53	54	1.2	1.3	9.5	9.2	−0.1	−0.1	5.2	5.2

It can be noted that PMV and PPD evaluations are a little better for bearable development, to the value of 10% during the hot part of the day. The result reflects the wind obstruction and the MRT scenario differences in the considered cases,

4.4. Design Workshop "Energy and Architecture" Results

As important part of this study, the workshop conducted in 2012 at the School of Architecture gave some results in more general terms. Students were asked to make an extensive research across Antofagasta city, focusing on luminic, acoustic and climatic preexistences. Then, they had to develop new proposals for residential architecture, resolving users' needs and ambiental items, using the observation of the city as a the foundament for design process.

Students founded few patterns in the Antofagasta apparence: the colours, the orientation of the streets, the horizon line of the sea and the mountain suggests a urban morphologi that respects these principal tensions. Paradigmatic modern buildings had been built under this concept, using some bioclimatic concept as seattlement, elongation, orientation to reach landscape integration and building comfortability.

Buildings like "Curvo" (Figure 12) or "Calice", examples of the Antofagasta modernity [26,27] are integrated in the city and contribute to generate an environment. The structure of the environment of the city, between mountains and ocean, suggests a building disposition that reflects this elongation. On the other hand, recent buildings, expecially in the first line in front of the sea, are not integrated in the natural nor in the urban context. Slenderness could cause some interferences in the right to views, irregular shadowing and ventilation, as shown for the "Avenida Brasil" case.

Figure 12. "Curvo" residential building (courtesy of Claudio Galeno).

Other results include acoustics and social consideration on the urban lifestyle. Tall buildings are exposed to farnoise, expecially the top floors. The same construction of this kind of buildings generates high levels of noise, much higher than street noises. People meet only in elevators and social activity is reduced to going to the supermarket, parking, *etc*.

A controlled building development has to consider a correct insertion of small commercial areas, services, green parks. With respect to dwelling distribution in the blocks, it is important to consider a double exposition (S-N) and place the stairwells outside or in an intermediate space, avoiding anonymous internal elevators and using the built space better. These kind of buildings do not affect the environment like the towers, and are less expensive in terms of construction and use [28].

Figure 13 shows the workshops' proposal for residential building distribution in different places of Antofagasta. The students' works show the possibility to conserve density and at the same time obtain an environment more attractive in aestetical terms. Proposed buildings integrate energy concepts, consider photovoltaic and solar thermal panels inclusion in design. Comfort has been considered in the proposal and projects include solar protections, galleries, wind protection or ways to cool the building, depending on the case.

With respect to density, the concept that is used to justify the vertical growth, it has to be remebered that differen design strategies could lead to the same density result with different buildings' distribution and hight. For example, as discussed by Pérez de Arce [29], Figure 14 shows different dispositions of urban structure with the same density result. During the UCN laboratory, students were asked for a new proposal that does not change the actual density parameters.

A change in building hight has an immediate consecuence on energy consumption of elevators, but at the same time is creating a different paradigm of colletive life, with substitution of anonimous elevators or enclosed stairwells with external plataforms, ramps and other circulations that at the same time encourage communication and desplacement of the inhabitants.

Figure 13. Some workshop proposals for bearable building designs in Antofagasta.

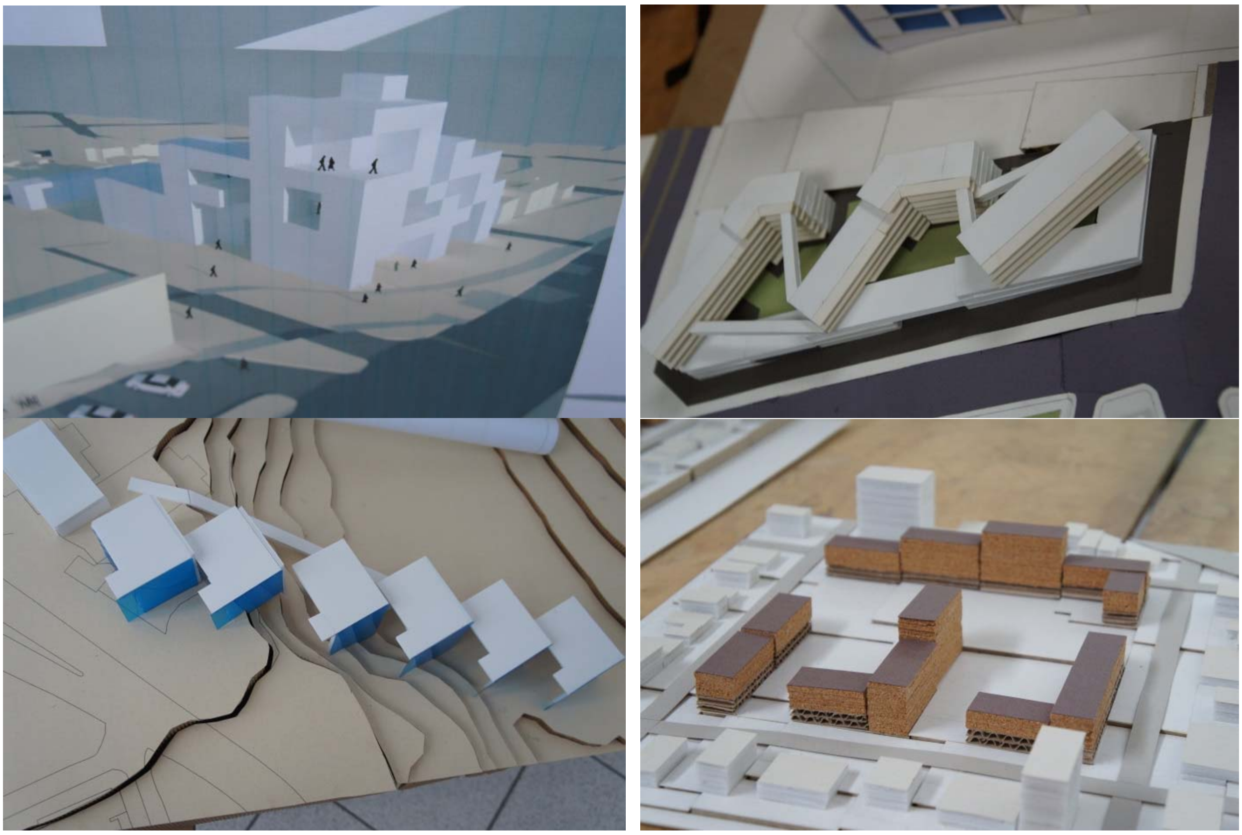
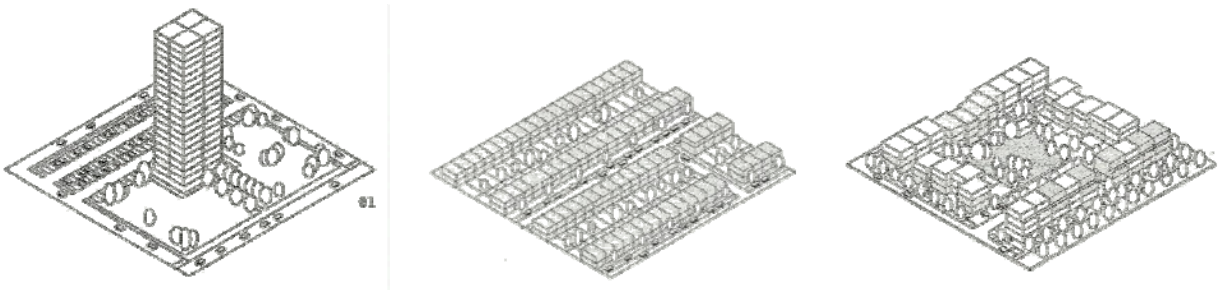


Figure 14. Different distribution with the same density (adapted from Pérez de Arce).



5. Discussion and Future Work

This research focused on the impact of towers construction near the green area of "Avenida Brasil" in Antofagasta. Simulation studies have been conducted to put in evidence the change in environmental parameters outside of new buildings. In addition, a workshop was conducted with students of the 5th semester of their architecture degree, searching for more general results, involving the entire Antofagasta city.

This research is a first attempt to generate a methodology to analyze and determine a design guide for urban development, suitable across the world but especially focused on development countries and hot, dry climates. In the desert, some big cities are being constructed and others are under development.

Medium sized cities, like Antofagasta, also have problems in modifying their morphology under iconic processes of urban renovation. Future tasks will be to understand better the consequences of the master plans under development at this time. For example, planned research at the Architecture School involves City Cad software use to estimate energy waste and CO_2 emissions related to different urban growth possibilities. Complexity of the studies will require an effort of different agents, public and private, to develop new methodologies and guidelines, including different visions and sustainable processes.

6. Conclusions

In conclusion, we can assume that the current trend in the Antofagasta urban development appears quite harmful. Buildings are expanding in the entire city, without any consideration of history, skyline integration, environmental sustainability, acoustics, *etc*. The only parameter taken into account is economic growth. Climate change, both in terms of global heating and secondary effects (ocean levels, tsunamis, *etc*.), can improve the risk of living in Antofagasta or in other towns that are developing their morphology in the same uncontrolled manner [30].

As teachers and students of architecture, in the UCN School we are working on a different proposal, a city that is expanding with certain degree of equilibrium between green areas, services and residential blocks, medium sized, that have to improve the social life in the city center.

This new city concept can be regarded as more sustainable, resilient and robust. Robust design seems to be an important concept to engage with when considering variability in climate, environmental condition and user behavior.

As described in some articles [31–33], robust and resilient cities can be the low-tech answer to a critical situation of unsustainable development, especially in the countries of the south hemisphere, where economic inversion in sustainable high-tech management is quite poor.

It is possible that tall buildings were a sustainable solution in some climates and societies, but related problems are not considered in the Antofagasta development case. Future work could be the simulation of a larger sector of the city center in order to understand better the ventilation dynamics and to establish a development guide respecting view rights and general environmental integration of new construction. As suggested by relevant authors since 1960 (see for example the urban development observations done by Victor Olgyay [34]), tall buildings can be considered, but in an organized city, possibly concentrating in a particular zone and well connected with the other urban sectors. The respect of the landscape line of the mountains seems to be one of the most important issues to taken in consideration for our case.

Conflict of Interest

The authors declare no conflict of interest.

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