HOUSING: Dense, high-rise buildings with green, low carbon solutions. Case study: Santiago, Chile.

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Abstract. Considering the international relevance of sustainability, Chile has implemented several regulations in the housing area during the last years through the Ministry of Housing and Urbanism. The goal of these regulations is to improve the performance of Chilean cities regarding the three pillars of sustainability (social, economic and environmental). Santiago, as the capital of Chile and the focus of this research, has defined different methods to apply these regulations. However, this city still has challenges to implement them, such as environmental pollution, social segregation and the lack of economic and natural sources. There are different alternatives to overcome the challenges to implement the new sustainable housing guidelines in Santiago, one of them is to rethink the current density, high and sustainable solutions that the buildings have. The main objective of this paper is to describe and analyse the situation of the housing in Santiago considering the density, high-rise buildings with green guidelines and low carbon solutions as analysis parameters. The methodology established to achieve this objective is exploratory-descriptive with the literature review technique. The partial results illustrate that despite the benefits that represent the incorporation of new guidelines related to the increase in density and high-rise and low carbon solutions in housing projects of Santiago, it is important to consider that not all of these are applicable to this city. Each territory has its features (weather, culture, resources and norms), which determine the requirements that the projects need and the real possibilities to implement changes.

Keywords: high-rise building, housing project, low carbon solution, green guidelines, Santiago - Chile.

1. Introduction

Sustainability is a significant concept in the Architecture, Engineering, and Construction (AEC) industry because it defines the guidelines that this business implements in projects. The Brundtland Commission defined sustainability as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [1]. This definition was complemented by the Agenda for Development established by the United Nations (UN) in 1997 with the description of three pillars of this concept: social development, economic development and environmental protection.

Internationally, there are two facts which illustrate the relevance of sustainability. First, the agreements established to define the sustainable goals for the future of the world. For example, the 17 Sustainable Development Goals (SDGs) of the UN [2] and the Paris Agreement signed in 2015 [3]. Second, the new green certifications for building and materials. For instance, Energy Start, Leadership in Energy and Environmental Design (LEED), and Green Globes [4].

Considering the international relevance of sustainability and the guidelines and certifications related to this topic, Chile has implemented three regulations in the housing area during the last years through the Ministry of Housing and Urbanism: The Sustainable Construction Code, The National Sustainable Construction Strategy and The Energy Rating of Housing [5]. The objective of these regulations is to improve the performance of Chilean cities regarding three pillars of sustainability. Santiago, as the capital of Chile, has defined different methods to apply these regulations. However, this city still has challenges to implement them [6]. For example, environmental pollution, social segregation and the lack of economic and natural sources.
There are different alternatives to overcome the challenges to implement the new sustainable housing rules in Santiago. One of them is to rethink the current density and the high and sustainable solutions that the buildings have. The main objective of this work “is to describe and analyses the situation of the housing in Santiago considering the density, high-rise buildings with green guidelines and low carbon solutions as analysis parameters”. This research is descriptive exploratory, and the methodology involves a bibliographic review.

The justification of this work is based on three reasons. First, exploring different guidelines possible to apply to Santiago as a possible alternative to improve the current situation of this city. Second, learning about two successful examples of sustainable high-rise housing. And third, studying different strategies to achieve at least 4 of the 17 SDGs of the United Nations (UN) [2], Goal 7: Affordable and clean energy, Goal 9: Industry, innovation and infrastructure, Goal 10: Reduce inequality and Goal 11: Sustainable cities and communities.

This research is organized into 5 sections. First, the introduction. Second, the methodology. Third, the description of the housing topic related to density, high-rise buildings with green guidelines and low carbon solutions and the description of two international successful examples. Fourth, the analysis of Santiago. Fifth, the exploration of possible guidelines to apply to Santiago. And sixth, the conclusion.

2. Methodology
In addition to the main objectives of this research, this work has four specific objectives:

1. To define the key concepts of this research: density, high-rise buildings with green guidelines and low carbon solutions.
2. To describe two successful examples of dense, high-rise buildings with green, low carbon solutions for housing considering the features of the city of Santiago.
3. To describe the case study: Santiago.
4. To explore new guidelines, from the case studies analysed, possible to apply in Santiago to improve the current situation of housing.

This research is exploratory-descriptive and uses the method of a literature review, which is focused on analysing information from secondary sources connected to the themes of this research, such as papers of relevant authors; books with peer editorial review; and reports from architecture and construction companies associated with the case studies.

The three criteria to define the two successful examples analysed in this paper were the typology of the project (residential), the climate condition (similar to Santiago) and the population (30% more or less of the inhabitants of Santiago).

3. Housing: Dense, high-rise buildings with green, low carbon solutions

3.1. Definition of concepts:

High rise buildings
Farouk defines high rise buildings based on the criteria of height as buildings which fit at least one of two criteria: height over 36m or height over 12 floors [7]. Another factor is the structural perspective, where a high-rise building can be defined as ‘the building that its height will be affected by lateral forces resulting from earthquakes & wind forces to the extent that such forces will play a major role in the process of design’ [7]. The uses of high-rise building vary between residential, commercial, administrative, office buildings, hotels and mixed-use buildings.
Green or sustainable low carbon buildings

A building can be named sustainable when it has the scarcest troublesome impact on the environment [8]. The sustainability can be represented through three perspectives: environmental, social, and financial responsibility. On the other hand, services or products that have less impact on environment and health can be named green. In the case of buildings that have fewer carbon emissions, they are called low carbon buildings [9].

The attractive indoor environment of buildings, higher quality of life, renewable energy use, and reuse and recycling of materials are substantial benefits of high-rise, dense, green, and low carbon buildings. Considering these advantages, these typologies of buildings are relevant for the future environment, because of the limited natural resources and the necessity of new methods and techniques in construction project management in order to minimize the effects of construction.

3.2. Successful international buildings

Two international projects were chosen to be analyzed considering the criteria explained in the methodology.

One Central Park is located in Sydney, Australia. This project has three main similarities to Santiago. First, the monthly average temperature which varies in Sydney between 13°C and 23°C and in Santiago between 9°C and 21°C. Second, the average humidity in Sydney is 71% whereas in Santiago it is 70%. Finally, the population of Sydney in 2017 was about 5.07 million [10], while the population of Santiago in 2016 was about 6.5 million [11].

One Central Park is a mixed-use type of building. It integrates residential, commercial, cultural, institutional, and entertainment applications and it provides four distinguishing sustainable features. A tri-generation energy plant which is run by natural gas and provides space heating and cooling energy by producing low-carbon thermal energy. This tri-generation energy plant reduces the greenhouse gas emissions by 190,000 tons over 25 years [12]. An on-site water recycling plant creates the opportunity for inhabitants to use 40-50 per cent less drinking water leading to saving money and drinking water supplies. The facility has hanging gardens that incorporate 23 green walls including over 35,000 green wall plants with 350 different species, occupying 1,200 sqm area of the façade. These vertical gardens give a unique view to the building and they purify the air [13]. In addition, the cantilevered heliostat made by a series of motorized mirrors reflects the daylight to the cantilever. There are 220 reflecting panels fixed in the cantilever and they bounce the light back to below spaces [13] (figure 1).

This project has received numerous awards that have for its structural ingenuity and sustainability measures, for example, Winner of the High-Density Development by 2015 UDIA National Awards and Winner of the Best Innovative Green Building (global) from MIPIM Awards 2015 [12].

One Central Park, through the use of different sustainable systems, provides advantages by producing energy through low carbon emissions, lowering water consumption by water recycling and maximizing natural daylight through a reflecting system. Nevertheless, it has disadvantages, as for example the high accuracy and order regarding plant pests and diseases and the expensive maintenance cost for the vertical garden.

The Solaire is located in New York, USA. The project has two main features similar to Santiago. First, the monthly average temperature which displays values in New York between 1°C and 25°C and in Santiago between 9°C and 21°C. Second, the population, which in New York in 2017 was about 8.6 million [14], while the population of Santiago in 2016 was about 6.5 million [11].
This project is a 250-unit apartment building and it implemented sustainability guidelines through four different methods. First, resident education about the benefits and daily components of sustainability, and behavior reinforcing communications and operations protocols. Energy consumption by residents is 24% less than the New York State code [15]. Second, onsite wastewater treatment, storage and reuse system located in the building’s basement. After a process of recycling and removing color and odor, the water is placed in the storage tanks. The treated water is used as flush water, make-up water for the cooling towers, and for irrigation. Third the cooling and heating system, implemented in all the apartments includes programmable thermostats that efficiently control four-pipe fan coil units providing heating and cooling all year. High-efficiency, variable-speed pumps, fans, and motors circulate ventilation air and water throughout the building, and the high-efficiency absorption chillers run on natural gas instead of electricity [15]. Finally, solar cells made by panels that become part of the façade structure, replacing the use of brick or glass. The material used is recycled silicon. The solar electric systems are sized to meet 5% of the base building’s non-residential electric load [15] (figure 2).

This Solaire provides advantages such as; well-insulated and sealed building envelope, centralized air filtration and seasonal humidity adjustment, integrated photovoltaic panels, on-site water treatment and 85% of construction waste recycled. However, it has disadvantages as higher initial and maintenance costs.

4. Case study: Santiago
The metropolitan area of Santiago is configurated by 32 municipalities and accommodates approximately 35% of the population of the entire country (INE, 2012). It is the biggest city by population (6.5 million inhabitants), density (393 ha/k2) and provides up to 50% of Chile’s total Gross Domestic Product (GDP) of the country (figure 3 and 4).

From an environmental point of view, Santiago is one of Latin America’s most polluted cities due to thermal inversion [16]. Considering this situation, the government of Chile has generated different alternatives to overcome this situation, for example, the creation of Chile’s National Environmental Commission (CONAMA), controlled agriculture burning, eliminating lead gasoline, prohibiting open fires, the introduction of tradable emissions permits, the introduction of a new transport system.
The municipalities of Santiago are aligned towards high rise buildings. This is due to the funding provided by the private sector. The north-east part of Santiago is an example of high-rise buildings, with high population and green areas density, which provide social and ecological value for their inhabitants. The parking system of the city is based on underground parking areas, limiting the above area necessary to provide this service [17]. These standards are not achieved in the other municipalities of Santiago. The lack of required green areas density and housing standards provided in these municipalities produce limited high-rise buildings which also do not meet the sustainable objectives.

Figure 3: Santiago, the capital of Chile [26].

Figure 4: Dwelling density at the census district level, 2011 [26].
The social and economic polarization of this city affects the urban landscape and the density distribution. The standard of housing such as dimension, localization, type of calefaction and quality of the design depends on the social and economic status of the inhabitants. The infrastructure is also unevenly distributed in the different areas of the city. For example, the green area for a person is also affected varying from 9 square meters per person in the north-east area (rich sectors) to below less than 3 square meters per person in other areas (poor sectors) [18] (figure 5, 6 and 7).

The distribution of housing in the peri-urban areas of Santiago indicates the low density of middle-class residences in these areas. The lack of middle-class inhabitants contributes to accentuate the social differences in these areas [19]. Some municipalities allow the construction of high-rise building and others prioritizing low density. The criteria to define the density and the height of the buildings depends on the goal of the municipalities and the number of resources that they have because these topics are related to available facilities that the territory has.

Figure 5: Socio-economic groups and location of neighborhoods. Blue and green areas are upper classes, red areas lower class. Green is park areas [17].
The concepts of high-rise, green guidelines and low carbon emissions were and are considered in the development of housing projects in Santiago, for example the project Exequiel González Cortés Housing complex: built in the 1960s by the government is considered relevant because it increased the density of the housing projects considering the accessibility to facilities and green areas.

Nowadays, projects, such as Amanda which is a 5-story residential building with the goal to improve the performance of the building and reduce the negative impacts in the environment implemented green guidelines and low carbon solutions thought the super insulation, excellent environmental quality and clean climatization [20].

Despite the existence of good examples of a high-rise building with green guidelines and low carbon emissions, there is a new trend of construction in Santiago which is defined as Vertical ghettos. The main features of these buildings are the lack of green and common areas, the limited natural sunlight and fresh air, high energy consumption product of the limited access to natural sources (for example, light and ventilation), restricted entrances and exits considering the number of residents, and the poor acoustic conditions (figure 8).

Figure 6: High-income neighborhood in Santiago [26].

Figure 7: Low-income neighborhood in Santiago [27].

Figure 8: Non-Green Buildings in Santiago [28].
In summary, the inequality of distribution of the population based on social and economic status is a relevant issue in Santiago. The development of the dense areas populated by inhabitants with middle to low incomes in high-density areas, which provide better infrastructure, services and green areas for their population is a challenge faced to achieve sustainable goals for the city. High standard buildings and infrastructure to the less wealthy areas of Great Santiago can only be provided through legislation and government initiatives. This would raise the well-being state of the city but is connected to political actions.

Based on these existing issues, the government of Chile has provided guidelines defined by the National Policy of Urban Development [21]. The focus of these guidelines is shifting towards providing residential buildings to citizens with all the required necessities. The goal is to implement a strategy that will contribute to produce a cohesive housing situation for all the inhabitants of Santiago and to achieve the sustainable housing objectives.

Table 1: SWOT analysis. Source: Own elaboration.

| Strengths | Weaknesses | Opportunities | Threats |
|-----------|------------|---------------|---------|
| Economic and development centre for the country. | Social and economic polarization. | Build denser urban areas. | Construction propensity in peri-urban areas. |
| Historical, cultural and architectural values of existing buildings. | Distribution of Green areas in sectors. | Provide better infrastructure and services. | Private sector construction tendency. |
| Existing areas with high rise buildings with social and ecological value. | Standard of housing in different sectors. | Existing National Policy of Urban Development. | |
| Existing parking areas below the street level. | Lack of infrastructure in different sectors. | | |
| | Low middle-class population in peri-urban areas. | Neighbourhood unit concept. | |

5. Analysis: New guidelines to Santiago
Considering the international cases analyzed and the current situation of Santiago, this research defined two typologies of guidelines possible to apply to this city. The first typology considers the design of the housing projects from an architecture and engineering perspective and the second, establishes relevant urban policies.

5.1. Design (architecture and engineering)
New technologies Followings are significant and appropriate technologies for applying in a high-rise building in Santiago that create sustainability:

On-site tri-generation thermal system: Tri-generation technology produces clean power and energy for buildings. This technology works with natural gas. It is compatible in Santiago because of the existing of natural gas resources. If the tri-generation system is installed on site, it will supply thermal and electrical energy for residents; therefore, the electrical energy will not transfer from hundreds of kilometers away. Tri-generation technology is environmentally friendly because it reduces greenhouse gases and increases air quality.
On-site water recycling plant: According to the weather and climate information of Santiago, the water recycling system is suitable to use, because of the considerable amount of humidity. The on-site water recycling plant is a significant environmentally sustainable technology. It provides the opportunity to use rainwater, groundwater, sewage water and irrigation water in a more effective way. In this way, it grants a solution for the lack of water resources in these days and also avoided a potential critical crisis in the future.

Solar panels: The weather and daylight statistics of Santiago justify the use of solar panels. These panels can be installed on the roof or on the facade of the building. Moreover, solar panels can also provide shade and shelter from the rain.

Rooftop Gardens: They increase the green area of Santiago. This technology reduces heat effect and water runoff. It also helps thermal insulation in the building and gives some social benefits for residents.

Energy efficiency: In this part, for increasing energy efficiency different alternative methods can be used. These methods reduce non-renewable resources usage and provide more efficient and environmental solutions. The use of solar and gas energy is used to provide electricity and also improve the efficiency of the HVAC system by using less energy. Using waste heat through different systems to achieve heating and cooling efficiency. Moreover, using the appropriate sensors in different spaces to reduce the amount of energy by inhabitants.

Design Specification: Achieving sustainable goals is an international practice that has been followed by different states. The states have developed different sustainable guidelines for construction purposes. The implementation of guidelines such as LEED, BREEAM, iiSBE, Green Globes, and CASBEE have achieved ranged success in sustainable goals. These guidelines can be used as the main base to create the national specification for Chile.

Building life-cycle consideration: Considering the life cycle of the building to reduce the perception of the big initial investment of money necessary to implement new guidelines and the reduction of the energy during the complete life of the building. One of the main problems with the life cycle cost of buildings is the emphasizes giving to the planning and construction process over the operation and maintenance process. The maintenance cost is at least three times more than the initial cost (design and planning) [23].

Utilization of specific international standards for life cycle assessment like ISO 14040 and ISO 14044 offers an opportunity to establish life cycle cost as a requirement for construction projects.

Mixed-use building design: Implementing high rise mixed-use buildings as areas which provide not only residential spaces for the residents, but also commercial, cultural, and entertainment spaces. This enhances social interaction and provides a better social environment.

5.2. Urban policies
People education: Sustainability is a concept that is reaching a widespread in the last few years. As a relatively new idea, it should be incorporated in the Educational system as a social concept. Students can understand it and later implement in society. Also, different educational programs within private companies and public institutions can provide lectures to develop the knowledge of the people.

New policies implementation: Social awareness is a key factor in understanding the benefits of achieving sustainable goals. The new guidelines can be realized, only if people have a complete understanding of the manner how the implementation of sustainable policies will improve their lives. The government should conceive extensive advertising campaigns to provide the population with an understanding of the impact of sustainability.
Private sector incentives: While the government produces policies related to construction requirements, the partnership with construction companies is essential to implementing them. Construction companies, as private businesses are income oriented. A partnership can be reached if different incentives are given for achieving sustainable goals. These incentives can be in the form of beneficial loans, tax discounts or subsidies for implementing sustainable technologies.

Professionals knowledge: The development of new technologies provides tools to achieve sustainable goals. However, their usage is confined to the possibilities and abilities to implement them. The process of implementing and maintaining these new technologies over the life cycle of the buildings can be feasible, only if there are specialists, capable of implementing the new technological systems and are capable of maintaining them.

Society integration through the design of the cities: The main problem in Santiago that affects its capabilities of achieving sustainable goals is segregation. This problem can be challenged, through striving towards integration and social cooperation. High rise buildings can provide social apartments. This helps integrate people with different social and economic capabilities or background with each other. Also offering more common spaces in buildings for residents.

6. Conclusion
During the last years, AEC industry has included several sustainable guidelines in housing projects. Nowadays, these new strategies have improved the design of the housings, their sustainability performance and the quality of life of the inhabitants. The conclusions are structured according to the four specific objectives defined in the methodology.

First objective: “To define the key concepts of this research: density, high-rise buildings with green guidelines and low carbon solutions”. Nowadays, there are several innovations and new material which allow the construction of high-rise and dense buildings decreasing their cost. These new alternatives represent a real possibility to re-think about the design of buildings, specifically housing projects because there are more opportunities to plan and develop cities. Another important parameter is the current advance of green solutions for buildings which not only contribute to reducing the environmental impacts but also to improve the health of the inhabitants and limit of economic expenses during the life circle of the buildings. In summary to discuss and define the appropriate density, high-rise and low carbon solutions for the housing projects of a city is crucial to analyse the current performance of the buildings and the quality of life of the people from this city and the sources available to make changes.

Second objective: “To describe successful examples of dense, high-rise buildings with green, low carbon solutions for housing considering the features of the city of Santiago”. Considering the examples analysed, the possible guidelines to apply to Santiago are diverse. These contemplate technological innovations, vertical gardens, mix-uses, energy efficiency according to the local characteristics and bioclimate design. Nevertheless, all these projects show disadvantages such as difficult and expensive maintenance and investment, errors in the design and execution and ignorance of the inhabitants on how to use the new technologies. These weaknesses are important to overcome if the goal is to reply to the guidelines of these buildings to other housings complex. For example, it is required to improve the knowledge of the professional and inhabitants in these areas to avoid mistakes during the design and maintenance, incentivize the private sector to invest in housing projects, strengthen the local norm and regulation and incorporate the sustainability guidelines and behaviours as part of the daily life.

Third objective: “To describe the social, economic and environmental areas of the Santiago”. The city chosen has a strong economy and a variety of landscapes and natural resources and several sustainable construction laws and urban regulations, however, the distribution of wealth is unequal, a situation that is reflected in housing projects. For this reason, this city is considered a suitable case of study because
the current situation of the guidelines to build and design housings can be improved through the analysis of the performance of other residential buildings.

Fourth objective: “To explore new guidelines, from the case studies analysed, possible to apply in Santiago to improve the current situation of housing”. The guidelines (architecture and engineering) examined contribute to understanding the existing variety of possibilities to design better housing complexes and also the necessity to discuss the policies that support these guidelines. The political, social, an economic context of Santiago determines the guidelines possible to apply, since the current law allows for new technologies and architectural strategies; the perception and the education of the inhabitant contribute to increasing the demand for environmentally friendly housing projects, and the resources of the city define the investment that it can do.

These four specific objectives contributed to achieving the general objective of this research: “To describe and analyse the situation of the housing in Santiago considering the density, high-rise buildings with green guidelines and low carbon solutions as analysis parameters”.

In summary, despite the benefits from the incorporation of new guidelines for increasing density and high-rise and low carbon solutions in housing projects of Santiago, it is important to consider that not all of these are applicable to this city. Each territory has its features (weather, culture, resources and norms), which determine the requirements that the projects need and the real possibilities to implement changes.

Considering the conclusion, the future research topics are the methods to implement and evaluate the new guidelines proposed to Santiago because it is relevant to study the feasibility to modify the current situation of this city and the availability of resources to do it. Without these studies, these guidelines only contribute to generating an academic discussion but not to change and overcome the housings deficiencies of Santiago in a practical manner. Another topic to deepen is the effects that the new regulations of Santiago such as The Sustainable Construction Code, The National Sustainable Construction Strategy and The Energy Rating of Housing, can produce improvement on the configuration of the city and the quality of housing.

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