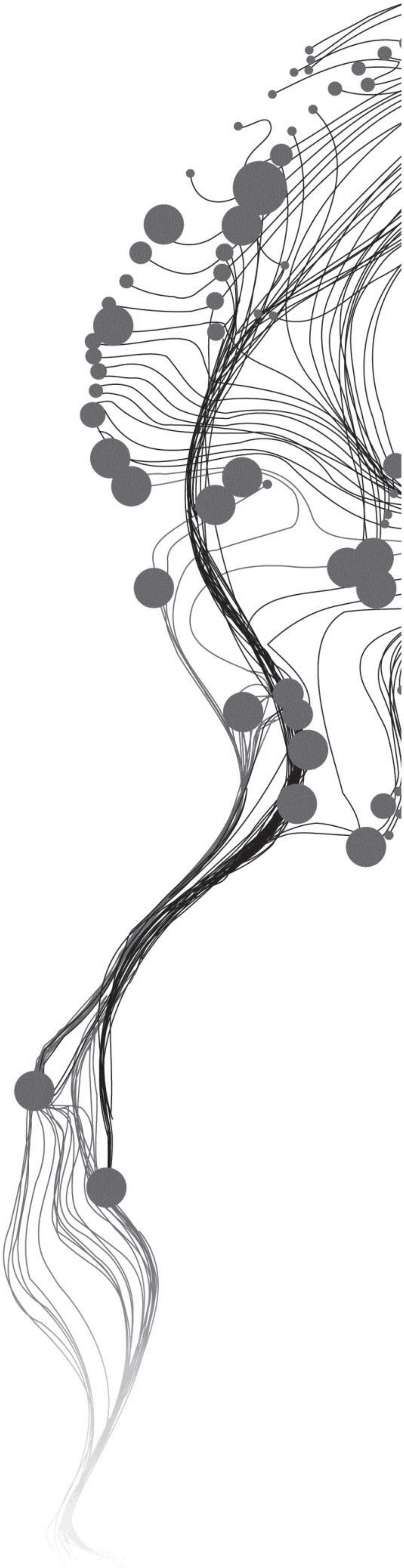
DEVELOPMENT OF ALTERNATIVE URBAN DENSITY SCENARIOS TO ACHIEVE A SUSTAINABLE URBAN DEVELOPMENT FOR THE CITY OF SANTA CRUZ DE LA SIERRA

MARIA FERNANDA ROMERO C.
March, 2012

SUPERVISORS:
Dr. J. Flacke.
Dr. J. Martinez.



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MARIA FERNANDA ROMERO C.
Enschede, The Netherlands, [March, 2012]

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SUPERVISORS:
Dr. Johannes Flacke
Dr. Javier Martinez

THESIS ASSESSMENT BOARD:
Dr. Richard V. Sliuzas (Chair)
Dipl. - Ing. Johannes Lückenkötter (External Examiner, TU Dortmund)
Dr. Johannes Flacke (1st Supervisor)
Dr. Javier Martinez (2nd Supervisor)

DISCLAIMER

ABSTRACT

A known an unavoidable reality is that the sustainability of the planet will be achieved in an urban development. When addressing sustainability one of the most important issues is the space consumption product of the urban development. Densities with which urbanized areas are occupied can have a significant impact on many aspects of sustainable development.

Santa Cruz de la Sierra is a fast grown city with an index growth of 5, 2% and with around 2.000.000 inhabitants. This amount of people generates a spatial demand that is expressed in a sprawl fragmented city with low density and many problems to be addressed. The study faces the problem of the fast urban development of the city through different urban density scenarios base.

The research approaches were: definition of Urban Sustainable Development, Collaborative Planning for the qualitative development and evaluation of the scenarios. The technical approach was the development of a 3D Model for urban density analysis and the modelling stage using Community Viz.

This research resulted in different urban density alternatives in 3d models for the City of Santa Cruz de la Sierra according to diverse policy options that helped to understand the impacts of different policies and to evaluate them towards a sustainable urban development of the city of Santa Cruz de la Sierra.

Results show that collaborative planning and scenario development are good tools to assess different impacts of policies options. The 3D model developed in this study could help to understand the impacts of the urban density in a more visualize way and could be a helpful tool to study how the urban context of a city may unfold after applying different urban density policies.

Keywords: Urban Development, Collaborative Planning, Scenario Evaluation and 3D model

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María Fernanda Romero Caballero
Enschede , February 2012

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1. INTRODUCTION

1.1. Introduction

A known and unavoidable reality is that the sustainability of the planet will be achieved in an urban environment as cities are growing in an exponential velocity and they are recognized as the engines of the human and urban development, where their performance and productivity is a question to be approached through an effective management that leads to a sustainable development.(Davidson, 1996).

A sustainable city is a concept that is linked to a better design of the urban environment, a good and rationale use of the land with an effective spatial planning for the future developments in a long term vision. The question of how to make the development of a city more sustainable is one of the most challenging issues and one of the most common problems that humans and cities are dealing with.

There are many theories on how to achieve urban sustainability, but it may not have been accomplished as the questions are still remaining. The central thinking on urban sustainability "is the belief that future generations living in cities are entitled to have secure access to essential resources needed to live, and that urban systems must be designed and developed to have the capacity for resilience."(Roberts, 2007). From this citation we can consider a sustainable city, a city which has dynamics, with well managed resources accompanied with good governance that is able to respond to critical scenarios and to innovate solutions for the physical changes and requirements of the development.

1.2. Background and Justification

Sustainability is seen by many as an essential requirement for human survival on planet earth, when addressing sustainability one of the most important issues is the space consumption product of the urban development. Cities have been growing in exponential ways and the definition of the adequate concept design and planning policies such as urban density are still on discussion. Much attention has put on the relationship between urban form and sustainability. Cities must be in a form and scale appropriated to walk, cycle and have an efficient public transport, with a compactness that inspires social interaction (Elkin, McLaren, & Hillman, 1991).

Densities with which urbanized areas are occupied can have a significant impact on many aspects of sustainable development. The density has impacts on the city structure and dynamics on a long term and, the effects are less evident in contrast with other planning policies. This makes it evident that the implementation of a certain urban structure and density is an important element towards sustainability.

This research aims to develop possible states of the future of the city of Santa Cruz de la Sierra that has a fast urban development and needs to visualize and be aware of what or how the future of the city could evolve in order to adjust the actual urban norms of the city towards a more sustainable development.

1.3. Research Problem

The world urban population over the past two decades has been growing at more than 1,7% per year, while the population density has decreased, producing a footprint growth of 3,3% annually, causing problems of management and sustainability according to the World Bank Report (Angel, 2005). This does express the need for a good urban management of the land as our limited resource.

Therefore, sustainable urban development is part of the main target to address in this era, due the challenges of the dramatically increase of urban space consumption within the last century , which calls for a better management of the land in order to ensure the equilibrium of the environment, economy and social needs through the development of the city.

Within these considerations there have been investigations that study urban density as an important indicator for targeting the goal of a sustainable urban development (Roberts, 2007) (Berghauser Pont & Haupt, 2009). Where density is a matter of performance, the right size or amount according to its performance and how it differs in specific contexts (Jacobs, 1961), is understood as how density has an impact on health, environment, productivity of the cities and human development.

As is mentioned before, the city of Santa Cruz de la Sierra is among the fifteen cities with a mayor population growth in the worlds ranking cities, with an index growth of 5.2% and around 2.000.000 inhabitants. This amount of people generates a spatial demand that in the context of the country and the weakness of the city management is expressed in a sprawl fragmented city with low density, that over estimates the capacity of the Local Government in order to provide a good respond to this fast growing development.

Subsequently its urban expansion is expressed in an actual footprint of 22.000 ha. that allocates 1.940.000 inhabitants. In addition to that, the out dated urban norms do not help the government to solve the actual problems or even the new problems that are to come. The latest research indicates that the footprint of the city has grown with in a 103% since 1995, which means that in the next twenty years it will be the doubled. The land consumption outside the established legal boundaries of the urban area (38.000 has.) of the city will increase, developing a city with over 3.000.000 inhabitants, with a very low density (less than 65 inhabitants per ha).

In this context the costs for the provision of basic services will be high, as well as the urban infrastructure and equipment. The very extensive low density will lead to problems like high costs of urban processes, without a good access to services as the land use is very zoned and the concentric city design does not comply with the new characteristics of the city, the population and its economic activities that demand a better systems of services with a good urban infrastructure and equipment.

Within these the city calls for a better management of the land in order to ensure the equilibrium of the environment, economy and social needs through a sustainable urban development of the city. The research problem of this study is summarized as follows: how to achieve a sustainable urban development for the city of Santa Cruz de la Sierra – Bolivia through a collaborative urban scenario development.

1.4. Research Objectives

1.4.1. Main Objective

The main objective of this research is to develop urban scenarios to support planning decision to achieve a sustainable urban development for the city of Santa Cruz de la Sierra – Bolivia.

1.4.2. Sub – Objective

1. To identify the different attributes of urban density that will help to address urban sustainable development.
2. To identify a set of sustainable urban indicators to measure urban sustainability of the city.
3. To identify the vision of the city of Santa Cruz de la Sierra, towards a sustainable urban development.
4. To develop different scenarios for the sustainable urban development of the city of Santa Cruz de la Sierra.
5. To measure the impacts of urban density in the city of Santa Cruz de la Sierra.
6. To assess the sustainable urban development of the city according to the new strategies implemented.

1.5. Research Questions

Objective one: *To identify the different attributes of urban density that will help to address urban sustainable development.*

- What is urban density?
- Which are the attributes of urban density?

Objective two: *To identify a set of sustainable urban indicators to measure the urban sustainability of the city.*

- What are the most adequate urban indicators for a sustainable urban development?

Objective three: *To identify the aim for the city of Santa Cruz de la Sierra, for its future sustainable urban development.*

- What is the vision of the stakeholders of Santa Cruz de la Sierra on the sustainable urban development?
- What is the vision of the new generation of architects of Santa Cruz de la Sierra on the sustainable urban development?
- What are the main drivers for the urban development of Santa Cruz de la Sierra?

Objective four: *To develop different scenarios for the sustainable urban development of the city of Santa Cruz de la Sierra.*

- What is urban sustainable development for Santa Cruz de la Sierra?
- What are the driving forces of the development of the city?
- What are the key planning strategies of the city of Santa Cruz de la Sierra?

- What are the assumptions and parameters to be implemented in the scenarios for Santa Cruz de la Sierra?
- Which uncertainties must be considered in the development of the different scenarios?

Objective five: *To measure the impacts of urban density in the city of Santa Cruz de la Sierra.*

- How to measure urban density?
- Which spatial tools are available to measure the urban density and sustainable development?

Objective six: *To assess the sustainable urban development of the city according to the new strategies implemented*

- Which scenario performs best under the new policies implemented?

1.6. Conceptual Framework

The conceptual framework is based on the three main concepts reviewed in this research: Urban Sustainability, Urban Density and Collaborative Scenarios in order to achieve a sustainable urban development for the city of Santa Cruz de la Sierra. The understanding of each concept and their more important definitions is studied in the literature review. In order to comprehend their relationship and importance towards the urban sustainable development, the development of collaborative scenarios and its applicability in urban planning is studied as well.

Figure 1 illustrates the three basic concepts studied and its relationship in this research towards finding a good output for the understanding of the future states of the city of Santa Cruz de la Sierra.

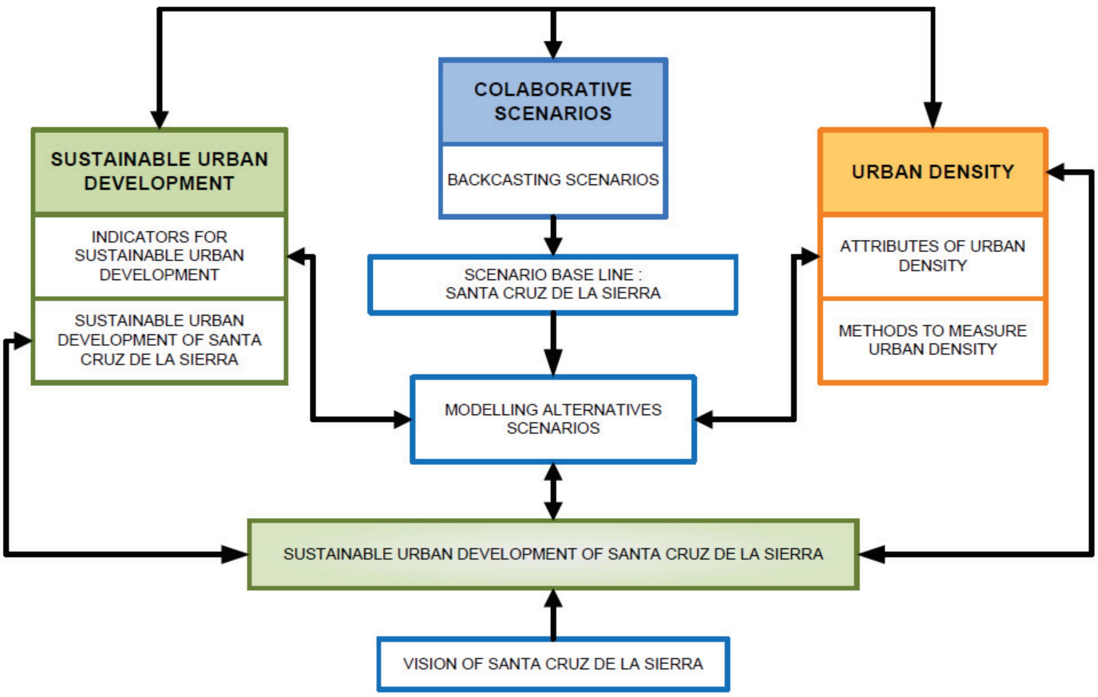


Figure 1 Conceptual Framework

1.7. Research Design

This research is divided into three parts. The first part discusses the three main concepts addressed: Urban Sustainable Development, Urban Density and Collaborative Scenarios, shown in Figure 1 above, which will support the design of the urban density model. In the second part, the methodological step converges with the first part to design and implement the urban density model. The third part is the evaluation of the results of the model that will help to answer the research questions of this study. The research then is finished with conclusions and recommendations for further studies.

1.8. Thesis Outline

Chapter 1

This chapter provides the introductory background information of the study subject and the justification. It also describes the research objectives, research questions for each sub-objectives and the conceptual framework of the research

Chapter 2

This chapter highlights the relevance of the three main concepts: Urban Sustainable Development and the different ideas of a good sustainable urban development. It also reviews the definition of Urban Density and its different units of measurement. After that the concepts of Collaborative Scenario are reviewed.

Chapter 3

This chapter provides a detailed description of the methodology defined in order to achieve the research objectives. It also presents a brief description of how the primary data was collected, the definition of the Scenario Base Line of the study area and the software to be used in the development of the scenarios. Finalizing with how the evaluation of the scenarios will be done.

Chapter 4

This chapter discusses and presents the data collection results of the fieldwork activity.

Chapter 5

This chapter is a brief description of the present condition of the study area, discussing its urban development history, its physical structure, demographic characteristics and administrative structure. It also presents an analysis of the actual urban norms related to the urban density of the city, its urban density and its land use distribution. The identification of different areas where new developments are taken place is also discussed.

Chapter 6

This chapter presents the basic elements of the scenario, the qualitative data and practical methods applied for the scenario development. Concluding with all the considerations made for the implementation of the model.

Chapter 7

This chapter models the different scenarios for the study area and presents the outputs of each state of the model: Suitability maps, Allocation Land Maps and finalizing with the 3D model of the city in the different scenarios defined.

Chapter 8

This chapter presents the scenario evaluation, the definition of the indicators and the outputs and discussion of the results.

Chapter 9

This Chapter presents the discussion of the results and the findings of the objectives.

Chapter 10

This Chapter presents the final conclusions of the research as well as the limitations and recommendations.

2. LITERATURE REVIEW

2.1. Urban Sustainable Development

As the world is inevitably becoming urban, "by 2030 all developing regions, including Asia and Africa, will have more people living in urban areas than rural areas" (HABITAT, 2010), so cities should look for solutions in the direction of a sustainable urban development. Therefore the concept of sustainable urban development has been studied and reviewed since the United Nations Conference on Environment and Development in Rio de Janeiro (1992) , many definitions of sustainable development and un-sustainability have been stated, but the current pattern of the world population growth suggest that it is one of the major causes of un-sustainable development, creating environmental degradation, serious natural resources and quality of life problems; specifically in urban areas.

Consequently, cities have taken a considerable attention as the main element to achieve; the sustainability, where different interpretations of the way to achieve this desired state has triggered an open debate between the experts on the subject that addresses different concepts and forms of sustainable cities, Luciano Ducci, mayor of Curitiba, the greenest city in Latin America refers to sustainability as a constant research. Richard Burdett, consultant advisor of the LSE Cities Programme and of the Mayor's Architecture and Urban Design Task Force considers that a sustainable city should be versatile, compact and beautiful. Anthony Giddens, a contemporary sociologist from the University of Hull and London School of Economics considers climate change one of the most important task to address in order to get sustainability, all these different understandings show the broader concept of sustainable development however all of them set an important role for the urban areas in determining whether sustainable development is an achievable goal.

Clearly the debate between a compact city and a sprawl city is an important matter considering how urbanization develops nowadays. Especially after the two conferences: HABITAT International (1997) and Rio + 10 in Johannesburg (2002) where some questions have been stated, such as: "what are the characteristics of urban sustainability? How do they relate to the urban form? How can they be scaled and tested?"(Roberts, 2007).

There has not been a consensus between these two positions as the sprawl city began its appearance in the 50's and 60's with the promise to provide for a better livelihood for the citizens that was taken away by the industrial revolution, and improving their environment with houses and greener areas away from the pollution of industrial cities. Nowadays the typology of the city is the normal expression of the rapid population growth and its fast urban development which does not go along with the planning of the cities in most of the developing countries; causing problems in all the elements of the urban system.

On the other hand, the compact city arises as part of the solution for a sustainable development looking at a good urban environment that has an efficient use of land as a limited resource, form and scale appropriate to walk, cycle and has the service of an efficient public transport. Such compactness will also encourage social interactions. This position explains the conclusions of Jenks, Burton and Williams (Jenks, Burton, & Williams, 2000) when they agreed that the compact city is the most suitable urban form.

Therefore, as the interpretation of sustainable urban development has such a broad and contextualised definition, the debate remains open for the research of the most adequate sustainable urban development for each specific case.

2.1.1. What makes a city sustainable

A sustainable city according to Rogers (1998): "must recognize that the city needs to meet social, environmental, political and cultural objectives as well as economic and physical ones"(Rogers & Gumuchdjian, 1998). The key attributes of the described city must include: "equitable access to basic services, beauty in its art and architecture, creativity to optimize human potential, resource efficiency and minimal ecological impact, ease of contact, mobility, integrated and compact communities and diversity"(Rogers & Gumuchdjian, 1998).

Through this line of reasoning, a city must be of "…a form and scale appropriate to walking, cycling and efficient public transport, and with a compactness that encourage social interaction"(Elkin, et al., 1991). Therefore much attention has been dedicated to the urban form and its relationship with sustainability, understanding that the urban form and density of cities can have important implications for their future(Jenks, et al., 2000).

Consequently strong arguments support the concept "a compact form is the most sustainable form" (Jenks, et al., 2000), arguing that a compact city is the strategy to reduce the urban sprawl , created in its extreme form "the 100 mile city" along the major routes causing loss of landscape and high cost for providing infrastructure (Sudjik, 1992), resulting in an increase of the dependence on a private automobile and it reduces the efficiency of the public transport; generating traffic congestions and environmental impacts. So, because of the high density and its mixed uses, it is reasoned, that reducing the length of the trips makes public transport an attractive option(De Roo & Miller, 2000).

Through the literature that looks for the solutions for sustainable developments, the United Nations Conference on Environment and Development in Rio de Janeiro (1992) and the Local Agenda 21, "calls for local friendly systems of public transport and non-motorized trip making, supported in turn by the compact city concept"(De Roo & Miller, 2000). Also in the European Union, the Green Paper on the Urban Environment expresses its special concern off traffic congestions, noise and pollution and they too "urge a mixed use development in existing areas, urban areas, more residential areas in inner cities, and focusing growth within existing urban boundaries"(CEC, 1990). The counterpart in the United States adopted the urban growth management programs for eleven states, which require cities and urban developments to formulate and implement plans that include urban growth margins, and detect and encourage compact developments(Burby & May, 1997).

Even though the solution seems to progress in more compact cities there are experts that considers that this claim "….is at the very least romantic and dangerous, and do not reflect the dark reality of economic demands, environmental sustainability and social expectations". Likewise, "Welbank (1996) observes a Europe that is looking for sustainable urban development through compactness, based on belief instead of rational foundations"(De Roo & Miller, 2000).

Consequently, Jenks, Burton and Williams confirm the weak relation between concept of development and the basis and testing of the concept of a compact city(Jenks, et al., 2000). They recognize that cities are complex systems as well as sustainability and that require the awareness of the costs and benefits of the recommended solutions, adapted to the local conditions, physical characteristics and policy arena of the local context(De Roo & Miller, 2000).

2.1.2. How to achieve a sustainable city?

Every time there is more necessity to find ways to achieve sustainable developments, which accomplish the goals for environmental, social and economic well-being that is appropriate for us and the future generations. The sustainable indicators are the tools that help addressing the sustainable concept by supporting the way that the decisions are taken and analysing their performance. One of the biggest challenges of the concept of sustainable development is how to make it operational and quantitative(Blanco, Wautiez, Llavero, & Riveros, 2001).

2.2. Urban Density

There is no collective definition or measurement for urban density as it has scientific and social meanings that differ according to how the numerators and denominators are used in different countries and how it is comprehended or defined.

In "its simplest, density is a number of units in a given area"(Forsyth, 2003). A more universal definition from The Oxford Dictionary states density as "the closeness of substance, crowded state" (Dictionary, 2004) while in physics it is "the ratio of mass to volume or by quantity of matter in unit of bulk"(Dictionary, 2004). Roberts in the field of spatial science defines density as "a measure of the concentration, grain, tightness of patterns, cluster or intensity of beings or substance within a defined space or territory"(Roberts, 2007). The concept that goes along with the description that Churchman states for the spatial density is, that "spatial density is created by a given number of people within different size spaces"(Churchman, 1999).

Furthermore, in the literature other concepts are found that used to analyse the issue of density and how it affects people's lives, which are perceived as density and crowding(Alexander, 1993). Perceived density is "an individual's perception and an estimate of the number of people present in a given area"(Churchman, 1999) and crowding is a negative perceived density by an evaluation of an individual. These two concepts are based on a principle that can be observed, analysed and evaluated in different ways, under different conditions, by different people in different background and countries(Churchman, 1999). This is not going to be discussed in this research as it is based on the physical and quantifiable dimensions of the urban density.

So, Urban Density is "the term used to describe the dimensions of relationships between attributes of urban substance and beings"(Roberts, 2007) that express behaviour or flow, becoming "relevant to environmental quality, transportation systems, physical infrastructure and urban form, social factors, and economic factors"(Hess, Sorensen, Parizeau, Urban, & Studies, 2007).

In the world, the urban density is usually measured in inhabitants per hectare or square kilometre and the international comparison between the different urban areas that approve taking general conclusions based on the relation between economic development, lifestyles and urban densities.

2.2.1. Measures of Urban Density

The idea exists that density is an objective and quantitative term(Hitchcock & Planning, 1994), but density is measured in many different ways according to the scale, the different numerators and denominators that are used in the different countries; which makes it difficult to compare the densities in the different countries (Alexander, 1993).

The main basic attributes of density are described below in Table 1, from which several combinations can be made according to the need of the study and the goals to achieve.

Definition	Numerator (population)	Numerator (dwelling/Plot))	CONSIDERATIONS
Population Density	Number of inhabitants per given area (Davidson, 1996). Measure of population concentration in an area(Roberts, 2007).		Population can change through time even when dwellings remain the same, not a practical measurement.
Residential Density (Parcel density)		Number of dwellings in a residential area (Churchman, 1999)	More robust as dwellings do not change over time and is mostly used to describe urban developments (Berghauser Pont & Haupt, 2009)
Gross Density			Is the most ambiguous because some areas will include land for purposes that serve a wider population than the specific area.
Net Density	Number of persons in an area divided by the net residential area. Excludes roads, parks, and other public lands. (Churchman, 1999)	Number of parcels in an area divided by the net residential area. Excludes roads, parks, and other publics land (Churchman, 1999).	
Street net density		Dwellings units divided by the area of the public street rights –of-way that provide access to the residential parcels. (Churchman, 1999)	
Floor area ratio (FAR)		Total floor area divided by the total area of the plot/parcel.(Davidson, 1996)	Known also as Land Use Intensity
Floor space index (FIS)		Same as FAR	Known also as Land Use Intensity

Table 1 Different attributes of density.

Coverage.- This concept is used " to express the relationship between built and non-built land"(Berghauser Pont & Haupt, 2009). Also this measure is used by Colin Rowe (1978) to visually represent coverage as the distribution of (built) mass and open space; which will help to distinguish spatial changes.

Spaciousness. - "is defined as the relationship between open space and total floor area, as a measurement of the quality of an urban plan"(Berghauser Pont & Haupt, 2009).Which is the equivalent of the Open Space Ratio (OSR) used to specify the amount of open space in an area.

2.3. Relationship between density and sustainability

This section discusses the relation of density and sustainability, trying to understand the role of density in addressing a sustainable urban development.

2.3.1. Social Sustainability

Social sustainability is the relationship between society, built environment (density) and quality of life, Chan and Lee (2007) define that social sustainability is about the progress and maintenance of the current and future well-being, while reducing social inequalities improving the quality of life; through the interaction within the society. Therefore density by the urban form could affect the human comfort affecting in aspects such as temperature, air quality, lighting level and ventilation flows. Meanwhile social interaction increases when common areas for passive and active recreation are within the residential area(Sivam & Karuppannan).
According to these concepts, in Figure 2 are shown the three elements that are going to be studied in the presented research: proper mix and balance of land use, provision of social infrastructure and recreational facilities and accessibility.

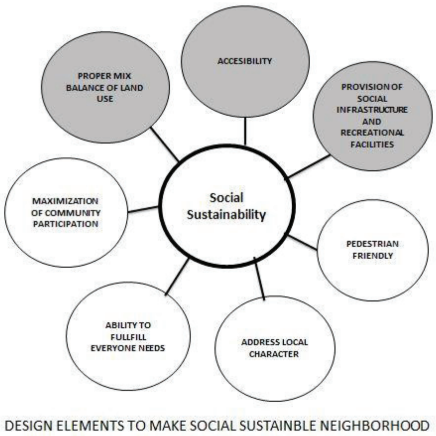


Figure 2 Design elements to make social sustainable neighbourhood.(Sivam & Karuppannan)

2.3.2. Economic Sustainability

The layout patterns and the spatial distribution of the activities and facilities are important elements that help to obtain economic gains, and density attempts to raise the utilization of land by providing high quality of high density housing to increase the total revenue(Fishelson & Pines, 1984).
So, the economic sustainability of a residential area is the outcome of the intensity of gross and net residential densities and various elements(Sivam & Karuppannan); mentioned below (Chan & Lee, 2008)

1. Optimisation of natural lighting and ventilation
2. Access to open space and social facilities for all age groups
3. Access to open space and social facilities for all age
4. Efficient use of land & space and mixed use development
5. Adaptability of development to the changing need
6. Green feature related to construction such as installation of energy efficient/water saving devices, use of recyclable and durable construction materials.
7. Provision of accommodation for different income groups
8. Layout pattern
9. Building design in terms of appearance, density, height and mass
10. Convenience efficiency and safety for pedestrian and public transport users.

(Chan and Lee, 2009, pp. 360-361)

Therefore, density and design parameters play a very important role to achieve economically sustainable development. In this research the elements to be studied are:

- ✓ Access to open space and social facilities for all age groups
- ✓ Efficient use of land and space and mixed use development.
- ✓ Provision of accommodation for different income groups.

2.3.3. Environmental Sustainability

Environmental sustainability is closely related to density through the design of the urban patterns which can affect the environment in a global and local level. Intensity of density has a significant role to make development environmentally sustainable, as well as the increase of density and mixed-use development means more buildings of different activities closer in distance that will encourage walking. It also empowers more efficient use of services and resources (Sivam & Karuppannan).

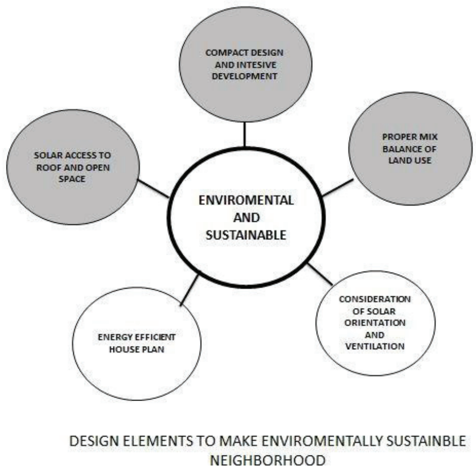


Figure 3 Design elements to make an environmentally sustainable neighbourhood(Sivam & Karuppannan)

The elements that are found useful for the research in the area of environmental sustainability are the compact design, intensive development and the proper mix and balance of land use showed in Figure 3.

Through this discussion it can be concluded that density is one of the main elements to be considered in order to achieve a social, economic and environmental urban sustainability as it has the potential to address the triple bottom line principles of sustainability. Although as several authors agree on the potential outcomes for sustainable urban development correlate to the variety of the design variables that includes social, cultural, economic, environmental, transport, housing, land use distribution, which gives the opportunity to manage and balance the sustainable problems.(Sivam & Karuppannan).

2.4. Scenarios for Planning Support

Scenario Planning support has been in the planner's tools for several years, and nowadays it is widely used as it gained popularity. This is because it contributes to modelling and planning alternatives states of the futures and also because it improves the quality of the decisions – understanding the trends and uncertainties that the scenarios unfold.

2.4.1. Scenario definitions

There are many definitions of scenarios that are broadly used in many contexts such as planning support decision, environmental assessment and business planning, which look for the future state. A more general definition states: "A scenario, as we use the term here, is not a prediction of what the future will be. Rather it is a description about how the future might unfold. Scenarios explore the possible, not just the probable, and challenge their users to think beyond conventional wisdom"(Jäger, Rothman, Anastasi, Kartha, & van Notten, 2008).Furthermore, scenarios are possible future states of certain areas representing different plausible conditions under several assumptions(Mahmoud et al., 2009).

Scenarios create stories about the future with an interpretation of the present, a vision of the future with a variety of paths that address various future options. They also explore what the paths to follow are in order to achieve a particular outcome(Jäger, et al., 2008).

2.4.2. Typology of scenarios

Qualitative Scenarios are descriptions of the plausible futures in words and visual symbols; it has a narrative text called storyline. It is very useful for representing the vision of different stakeholders and experts at the same time with the disadvantage that it lacks numerical information at the moment to analyse the outputs. Quantitative Scenarios are modelled in equations with numerical tables and graphs. The advantage is that the assumptions are numerical and show exact numbers. The disadvantage is that the results are from computer modelling and many implicit assumptions about the future are made.(Alcamo, 2001).(Vitriani, 2010)

Furthermore, Borjerson et all. (Börjeson, Höjer, Dreborg, Ekvall, & Finnveden, 2006) describes the scenarios in three categories: Predictive which has the forecast and "what if" scenarios. The second category is the Explorative which includes the external and strategic types. Finally, the third category is the Normative scenario that preserves or transforms the scenarios. In this classification all the scenarios have a qualitative and quantitative part based on the main question of what can happen? , what will happen? , or how can you achieve a certain target.(Vitriani, 2010)

Another author (Mahmoud, et al., 2009) also classifies the scenarios in Exploratory that describes future states according to the known process of change and investigations of the past; in Anticipatory scenarios that are the result of a desired or feared vision of the future that can be accomplished or avoided according to different actions taken.

2.4.3. Scenario Development approach

Scenario development approaches are stated with some exercises such as the scenario development approach used in LCA (Life Cycle Assessment) that use "what if" scenarios, LCA is generally used in processes for business environments as the approach enables the researcher to set the hypothesis on the basis of existing data. (Pesonen et al., 2000). This approach consists in the definition of the scenario space and its key driving forces thought for the future, then the key measurements are define and probable situations that shape the scenario in several ways to finally report the results for the documentation. Alcamo (Alcamo, 2001), developed the SAS (Story and Simulation) approach for policy studies in the developing world water scenario. In this approach a story line is developed by the stakeholders and experts, followed by the use of models to quantify these qualitative descriptions and in the end to finalize with the communication of the scenario results. In this approach the stakeholders participate in the entire process. (Vitriani, 2010).

Other approaches in literature such as Borjerson (Börjeson, et al., 2006) that starts by collecting and generating ideas to some parts of the future as well as collecting data that involves the stakeholders. After that the model part is structured when the quantitative and qualitative parts are integrated to develop the scenarios to finalize meanwhile ensuring the consistency of the scenarios. For Mahmoud(Mahmoud, et al., 2009), the scenario approach has five steps: the scenario definition, the scenario construction, the scenario analysis, the scenario assessment and the risk management. In almost all of the phases all stakeholders participate. (Vitriani, 2010).

Plata-Rocha (Plata-Rocha, Gómez-Delgado, & Bosque-Sendra, 2011), describes a methodology to develop scenarios for spatial planning for urban growth that identifies the following steps: Qualitative description of the scenarios, the systems dynamics or based model , the simulation and allocation of the urban growth and the analysis and evaluation of the results.

A more generic approach is proposed by Jager (Jäger, et al., 2008), that defines three main steeps : clarifying the purpose and structure of the scenario exercise , laying the foundation for the scenario and developing and testing the scenario.

2.4.4. Review of different approaches to develop scenarios in urban planning.

There is still a little orientation needed in the approach to develop a scenario in the planning field, even though the practice of the scenario for planning purposes has been used for several decades and the extended list of examples shows that scenarios not only models and plan alternative developments but also improve the quality of decision-making.(Song, Ding, & Knaap, 2006). Definitions of what scenarios should be is one of the guidelines for the approach in which Xiang and Clarke (Xiangô & Clarke, 2003) proposes three main concepts: "a good scenario creates surprising and plausible futures by incorporating future uncertainty", followed by "scenarios used vivid information in their composition and present information in a vivid way" and finally "for the design of the scenarios the number of themes or dimensions , size and the timeframe….should carefully chose so that the scenarios can interact with the user friendly". Considering that scenarios are created based on assumptions of possible changes rather than to avoid methodological bias in the definition of the scenarios and misunderstanding of the results , the perception of the scenarios should be explicit (Shearer, 2005). Defining issues such as why the study is taken, what will change or not in the horizon of the scenario.

Finally Yan Song (Song, et al., 2006), introduces a three step scenario approach that consist of reviewing the current planning systems and understanding the general context of the urban development and planning policies. Then an analysis of the existing urban development patterns is performed where the study identifies population growth, demographics characteristics, exiting land use patterns that reveal the possible new urban developments of the study area. In the end the scenarios defining the prior policies and framework are drafted, identifying the key elements of the study.

3. METHODOLOGY.-

This chapter presents the methodological approaches used to answer the research questions defined to achieve the main objective of this study. The city of Santa Cruz de la Sierra is used as the study area.

3.1. Research Process.-

This research was conducted using a case study methodology to discuss the problem by combining qualitative and quantitative methods. The qualitative techniques are applied to the implementation of the scenarios while the quantitative processes are used in the modelling stage of the analysis and evaluation of the different plausible future states of the study area. Also discussed are how the data collection was conducted and how the data analysis is done. Figure 4 shows the operational stages of this research.

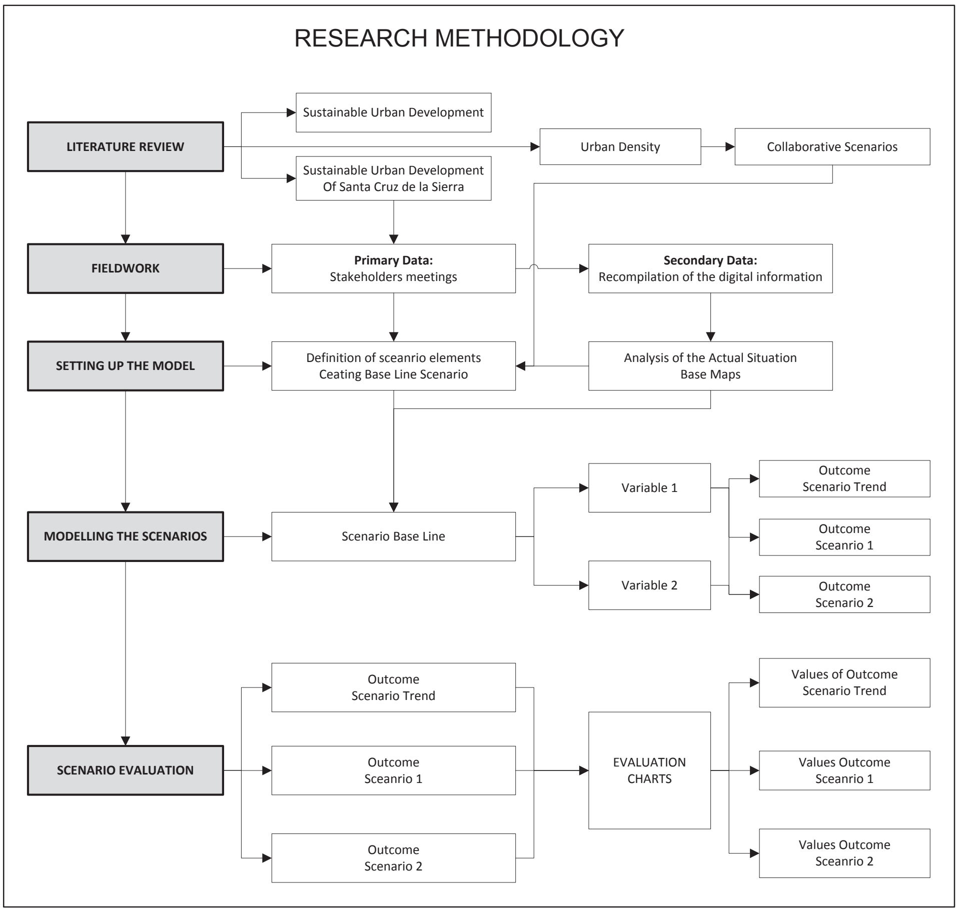


Figure 4 Research Methodology

3.2. Research Matrix.-

Research Questions			Data Requirement	Method of data analysis
Obj.1	1.1	What is urban density?	Concepts/Definitions	Literature Review
	1.2	Which are the attributes of urban density?	Definitions and comparison	Literature Review
Obj.2	2.1	What are the most adequate urban indicators for a sustainable development of the study area?	Primary Data Collection: Stakeholders Interviews / Documents Review/ Work Group FCM	Documents Review and Stakeholders interviews.
Obj.3	3.1	What is the vision of the stakeholders of the study area for its sustainable urban development?	Primary Data Collection: Stakeholders Interviews. Documents: Planning Strategies	Documents Review and Stakeholders interviews.
	3.2	What is the vision of the new generation of architects (students) of the study area for its sustainable urban development?	Primary Data Collection: Work Group FCM	Work Group
	3.3	What are the main drivers of the urban development of the study area?	Primary Data Collection: Stakeholders Interviews. Documents: Planning Strategies	Documents Review and Stakeholders interviews.
Obj.4	4.1	What is urban sustainable development for the study area?	Primary Data Collection: Stakeholders Interviews. Documents: Planning Strategies	Documents Review and Stakeholders interviews.
	4.2	What are the driving forces of the development of the study area?	Documents: Planning Strategies	Documents Review.
	4.3	What are the key planning strategies of the study area?	Documents: Planning Strategies	Documents Review.
	4.4	What are the assumptions and parameters to be implemented in the scenarios for the study area?	Primary Data Collection: Stakeholders Interviews. Documents: Planning Strategies	Documents Review and Literature Review
	4.5	Which uncertainties must be considered in the development of the different scenarios?	Primary Data Collection: Stakeholders Interviews. Documents: Planning Strategies	Documents Review and Literature Review
Obj.5	5.1	How to measure urban density?	Concepts/Definitions	Literature Review
	5.2	Which spatial tools are available to measure the urban density and its impact on the sustainable urban development of the study area?	Concepts/Definitions	Literature Review
Obj.6	6.1	Which scenario performs best under the new visions?	Concepts/Definitions Primary Data Collection: Stakeholders Interviews.	Literature Review

Table 2 Research Matrix

3.3. Data Collection Techniques.-

3.3.1. Collection of Primary Data – Stakeholders vision

The primary data was collected through interviews and discussions with the main actors of the development of the City of Santa Cruz de la Sierra, who are mainly professionals related to the area of planning and other players that are developers and academics of the study area. Table 3 presents the description of the stakeholders.

The criteria used for the selection of the stakeholders were done according to their participation in the planning activities of the city, such as: Local Planning Authorities and Past Local Authorities. Also the selection was done because of their contribution in the development of Santa Cruz de la Sierra, such as developers and Academics that are well known in the planning area. All the interviewed persons have participated or will participate in one way or the other within the planning development of the city. So their knowledge and experiences are very important for the understanding of the city development and to know what their expectations are for the future. The interviews also helped to get information about the actual situation of the study areas as well as obtaining documents about the key planning strategies of the study area.

Interviewers	Number	Criteria
Local Authorities (actual and past)	5	Actual vision of the Planning Office / Urban Norms and future plans.
Developers (Private Architects and construction companies)	3	Visions from different actors.
Academics	3	People that study the city and its development.

Table 3 List of Interviews

The interviews were conducted by the author with open questions in order to understand and to identify the visions, expectations and future improvements for the study area, as well as the main drivers of the city development. The main topics to be addressed during the interviews were:

- GROWTH OF THE CITY.
- LAND USES NORMS.
- URBAN DENSITY: FAR AND NET DENSITY

During the interviews the following questions were asked and according to the answers the discussions were established.

- ✓ How do you see Santa Cruz de la Sierra in the next 20 years?
- ✓ How much bigger will the city grow according to your expectation or vision?
- ✓ Which areas do you consider needing a special treatment?
- ✓ Do you think the land use and actual norms are adequate for the city?
- ✓ Do you consider the density of the city adequate?
- ✓ Where do you consider the urban density to be increased (FAR) (Building Heights)?
- ✓ Do you have any suggestions for the design of the *unidad vecinal* [neighbourhood unit]?

3.3.2. Collection of Primary Data – Indicators for assessment.

Other primary data collected were the variables of what could make the city of Santa Cruz de la Sierra a sustainable city. For this part a workgroup discussion was developed with students from the Public University of Santa Cruz that are in their fourth year of Architecture and Urbanism. This student class was chosen because of their advantage in their studies and their knowledge of the city and topics related to planning.

The activity was performed in a work group session with 30 students, where the students were asked: "what makes the City of Santa Cruz de la Sierra a sustainable city?" A brainstorm of concepts and definitions was collected from the discussion and then from these ideas a selection of the most important concepts and definitions was made by voting. From the final selection a definition for the indicators was created in accordance with all participants.

3.3.3. Collection of Secondary Data.-

The secondary data collected includes spatial information such as a database of the city, shape files of the different administrative levels, road networks, public transport networks, land use maps and satellite images of the study area. There is also non-spatial data such as census data, government reports and strategic plans for the city. These data were used to determine the present situation and to understand the established planning vision and directions of the study area. Table 4 shows the list of the secondary data collected.

Data	Date	Format
Administrative Units of the study area	2009	Shapefile
Land Use map	2009	Shapefile
Network roads	2009	Shapefile
Public Network (bus lines)	2009	Shapefile
Network of schools and health centers	2009	Shapefile
Demographic data	2001	Excel file and shapefile
Satellite Image	2009-2010	Digital image
Land Use norms	1980	Digital book
Strategic Plan 2015	2009	Hard copy

Table 4 List of secondary data collected

The land use maps, the city growths data and the demographics and social data are important elements to building the scenario base line and to model the next phases.

3.4. Developing Scenario Base Line of the study area.-

The base line scenario is the result of the analysis made in the previous stage with mainly the analysis of the secondary data, as a diagnosis of the basic elements that the city has, identifying the special areas and creating the basic elements and definition of the indicators for the urban density analysis. All these elements are a result from the information of the interviews.

The trend forecast of the population growth will later on be converted into the land use demand that will complete the elements of the scenarios.

3.5. Developing Different Scenarios for the sustainable urban development of the study area.-

The process of the scenario development will be done through the "CommunityViz" software. This software is chosen because of its ability to facilitate the vision and comparison of the different scenarios, and because of the flexibility to customize the user's needs. All the results from the modelling stage were visualized into maps showing the different possible scenarios of the study area through the next 20 years.

3.6. Scenario Evaluation.-

The scenario evaluation will be done with the four indicator selected in the fieldwork.

4. DATA ANALYSIS AND INTERPRETATION

This chapter discusses the methods applied during fieldwork to acquire the inputs for the scenario development and to select the indicators for the scenario evaluation.

4.1. Primary data analysis and interpretation.-

In this research two methods of data collection have been applied in order to obtain two different types of results. The first method applied was the stakeholders' interviews to collect the qualitative description of the future scenarios for the city of Santa Cruz de la Sierra. The second method applied was a group discussion to obtain some indicators for the assessment of the scenarios that were relevant for the students based on the actual problems that the study area is experimenting with.

4.1.1. Primary data analysis for the qualitative description of the scenarios.-

The primary data obtained by the answers of the interviews are used for developing the next plausible futures of the study area, which helped to create different scenarios of the city of Santa Cruz de la Sierra. Also the interviews facilitated to identify the most relevant areas of the city that need a specific treatment as well as some relevant elements of the city that will help in the modelling stage.

In the data collection methodology it has been explained that the main topics addressed in the interviews were: urban growth, land use norms and urban density. According to the discussions and from the answers obtained a matrix of new ideas that were mentioned was developed by each group in order to identify new visions of the city. Table 5 presents the main visions of the developer's group's interviews.

- ✓ **Group 1– The Developers.-**

Issue	Developer 1	Developer 2	Developer 3
Urban Growth	Control of Urban Growth	Control of Urban Growth	Control of Urban Growth
	Keep natural areas open	Rural land must be conserved	Expansion according to the urban radio
		No more expansion	Build on all empty parcels
Land Use Distribution (Urban Norms)	More Mixed Land Use in the city.	Core area of neighbourhood must have a diversity of uses.	More mixed land use to achieve a better communication within the areas.
Urban Density: FAR	Increase the FAR coefficient in all the parcels according the sector of the city	FAR coefficient must be higher than the actual	Higher Buildings (increase of the coefficient of FAR in the parcel) according to the land use
Urban Density: Net Density	Between the first to the 5th ring of the city the density must be increased.	Increased to four floors in most of the areas.	

Table 5 Matrix of Developers Group

The developers interviewed were concerned about the urban expansion of the city and they suggested an increase of the FAR in most parts of the city, which will help them to increase their revenue in the projects that they developed and to offer a better condition to the inhabitants with their projects. The opportunity to have a more mixed land use in different areas of the city helps to develop different projects besides the residential ones; and create new areas of commercial activity. The next group were the academics whose answers are shown in Table 6.

- ✓ **Group 2 – The Academics.-**

Issue	Academician 1	Academician 2	Academician 3
Urban Growth	Control of Urban Growth	Empty areas within the city must be developed before expanding to more land.	Control of Urban Growth
Land Use Distribution (Urban Norms)	Master Plan is good.	Core area of neighbourhood units must bring more services to its inhabitants.	The city has many typologies according to its socioeconomic situation and must be expressed in their norm.
Urban Density: FAR	Increase the FAR coefficient in all the parcels according to the urban norm	FAR coefficient as actual norm is good	Higher Buildings (increase of the coefficient of FAR in the parcel) according to the land use
Urban Density: Net Density	According to the results of the FAR density and the need of the area		

Table 6 Matrix of the Academics Group

Between the academics the expansion of the city is also one of the main problems and for that reason they suggest that the increase of the FAR is a solution, especially for the main roads of the city network. The road network must be completed and must control the growth of the city. In some areas of the city the land use flexibility will incentive a better development. Another important concern was the accessibility to jobs and the creation of them, as the urban sociologist mentioned. Table 7 – 8 is for the group of Local Authorities.

- ✓ **Group 3 – Local Authorities.-**

<table>
<tr><th>Issue</th><th>Local Authority 1</th><th>Local Authority 2</th><th>Local Authority 3</th></tr>
<tr><td rowspan="2">Urban Growth</td><td rowspan="2">Control of Urban Growth</td><td>Control of Urban Growth</td><td>Control of Urban Growth</td></tr>
<tr><td>Urban Radio must be reduced to control the urban expansion.</td><td>Get more public spaces and consolidate them.</td></tr>
<tr><td>Land Use Distribution (Urban Norms)</td><td>Urban Centralities are important to decentralize the city.</td><td>Stimulate Urban centralities in different areas of the city.</td><td>Identify areas to develop new centralities with a mixed of land use.</td></tr>
<tr><td>Urban Density: FAR</td><td>Increase the FAR according the width of the roads.</td><td>Must keep FAR as the Urban Norm established.</td><td>Increase FAR in main roads.</td></tr>
<tr><td>Urban Density: Net Density</td><td></td><td>Must increase to control the urban expansion.</td><td></td></tr>
</table>

Table 7 Matrix of the Local Authorities

<table>
<tr><th>Issue</th><th>Past Local Authority 1</th><th>Past Local Authority 2</th></tr>
<tr><td rowspan="2">Urban Growth</td><td rowspan="2">Control of Urban Growth</td><td>Control of Urban Growth</td></tr>
<tr><td>Restore the urban radio according the growth of the population</td></tr>
<tr><td>Land Use Distribution (Urban Norms)</td><td>Land use must follow as the Master Plan has established.</td><td></td></tr>
<tr><td>Urban Density: FAR</td><td>Residential Areas must keep the same FAR.</td><td>Keep FAR as the Urban Norm and Master Plan established.</td></tr>
<tr><td>Urban Density: Net Density</td><td></td><td>The Net Density is according to the design of the city; “Garden City”</td></tr>
</table>

Table 8 Matrix of the Past Local Authorities

The Local Authority group also considers that the expansion is an issue that needs to be controlled, although there are some that agree with the urban expansion that the city has now. The rest of the urban norms according to the group must be as the Master Plan has established so far.

A matrix has been developed with all the visions of the different groups in order to identify the trends for the future developments of the study area. In these processes many common elements were found between the different groups, such as the control of the urban growth which also was the main request from all the stakeholders interviewed. On the other hand there were also some differences of opinions found between peers of the same group that discuss the different policy options for the urban density of the city of Santa Cruz de la Sierra.

These results are due to the different stakeholder's background interviewed, in order to achieve a more reliable data and avoid any bias on the data acquisition. Table 9 shows the results where according to the topic addressed the visions of the different stakeholders are identified with the same darker grey tone.

Stakeholder	TOPICS			
	Urban Growth	**Land Use Distribution (Urban Norms)**	**Urban Density: FAR**	**Urban Density: Net Density**
DEVELOPERS GROUP	Control of Urban Growth	More Mixed Land Use in the city.	Increase the FAR coefficient in all the city	Between the first to the 5^{th} ring of the city the density must be increased.
	Control of Urban Growth	Mix land in core area of the Neighbourhood.	Increase the FAR coefficient in all the city	Increased to four floors in most of the areas.
	Control of Urban Growth	More Mixed Land Use in the city.	Increase the FAR coefficient in all the city (according to the land use)	
ACADEMIC GROUP	Control of Urban Growth	Master plan is good.	Increase the FAR coefficient in all the parcels.	
	Control of Urban Growth	Mix land in core areas of neighbourhood.	FAR coefficient as actual norm is good	
	Control of Urban Growth	More Mixed Land Use in the city.	Increase the FAR coefficient in all the city (according to the land use)	
LOCAL AUTHORITY GROUP	Control of Urban Growth	Urban Centralities are important to decentralize the city.	Increase the FAR according the width of the roads.	
	Control of Urban Growth	Stimulate Urban centralities in different areas of the city.	Must keep FAR as the Urban Norm established.	Must increase to control the urban expansion.
	Control of Urban Growth	Identify areas to develop new centralities with a mixed of land use.	Increase FAR in the main roads.	
PAST LOCAL AUTHORITY GROUP	Control of Urban Growth	Land use must follow as the Master Plan has established.	Residential Areas must keep the same FAR.	
	Control of Urban Growth		The Net Density is according to the design of the city; "Garden City"	The Net Density is according to the design of the city; "Garden City"

Table 9 Final Matrix

4.1.2. Primary data analysis for the indicators selection.-

The second activity done to collect the primary data was the group work where a list of possible indicators was collected to help to evaluate the future plausible scenarios modelled according to the visions and strategies established with visions identified in the previous steps. In table 10 the complete list of indicators and the selected indicators are shown. These indicators area a result of the fieldwork activity mentioned in section 3.3.2 of chapter 3.

Indicator	Votes	Indicator	Vote
Accessibility to different services	25	Land Use mixes	9
No Road congestions	21	Pea tonal Roads	7
Public Transport	15	Good Design of shelters	6
Green Areas	15	More residential areas	6
Good Roads	14	Good Urban Planning policies	4
Waste Collection	14	Keep Rural land (empty land)	3
Basic Services	13	More Jobs	2

Table 10 List of indicators collected

According to the most voted indicators, the author selected 4 of the 14 indicators base on the following criteria: Accessibility to different services and road congestion are linked indicators that will assess the interconnection of the different areas of the city as well as with the basic services. Green Areas and Keep Rural land also are related indicators that could help to analyse the consumption of the land in the city.

4.2. Secondary data analysis and interpretation.-

The Secondary Data related to the shape file of the study area and the Planning Documents were collected through the office of Cartography located at the Mayor Planning Office of the local government of the city of Santa Cruz de la Sierra. The census was collected through the internet pages of the INE (Institute of National Statistics) and the office of Cartography.

The present conditions of the study area were assessed with the Secondary Data including the physical and non-physical situations. It also helped to create the base maps to analyse the different impacts of the density through the different indicators selected for the activity realized during the fieldwork.

The strategic planning documents are used to understand the visions of the actual authorities and goals for the city. The review helped to identify the driving forces of the city and the key elements that will be part of the model.

5. ANALYSIS OF THE PRESENT CONDITION OF THE STUDY AREA

This chapter gives a brief description of the geographic location, the administrative structure and the present conditions of the study area. It analyses the present development, the demographic and land use of the city. Finally, it discusses the urban density and urban norms of the city.

To understand the actual situation of the city of Santa Cruz de la Sierra it is very important to know how the city has been developed until today including all the strategies and plans that the local government have made.

5.1. Urban Development of Santa Cruz de la Sierra.-

Nowadays, Santa Cruz de la Sierra is the second largest city of Bolivia located in the tropical part of the country, with a population of 2.029.471 inhabitants. The product of its 5.08% index of growth places it among the 15^{th} mayor population growth cities in the world ranking (Foundation, 2012). The city has become the centre of the economic force of the country that has 70% of the non-traditional exportations (soy beans, soybean meals, wood products, cattle, cotton and genuine leather, among others) of the country, and a strong economic structure that reflects a modern globalized city very much active in the industrial, commercial and financial activities.

Within all these considerations the urban growth of the city is a clear expression of the exponential fast development of the city as well as its characteristic of being the engine of the development in Bolivia. In the colonial period of the country (1943), Santa Cruz was not part of the main cities coming to regard the city as a peripheral city, with no more than 200 blocks around the main square, keeping its classic damero structure and 32.000 inhabitants (Figure 5). As a consequence of the deteriorated miner economy, ten years later, the petroleum, agriculture and cattle show the potential opportunities of the city that are accompanied with the construction of the main highway to connect the city with the rest of the country. This causes first representative growth of the city, with 50.000 inhabitants by the year of 1957.

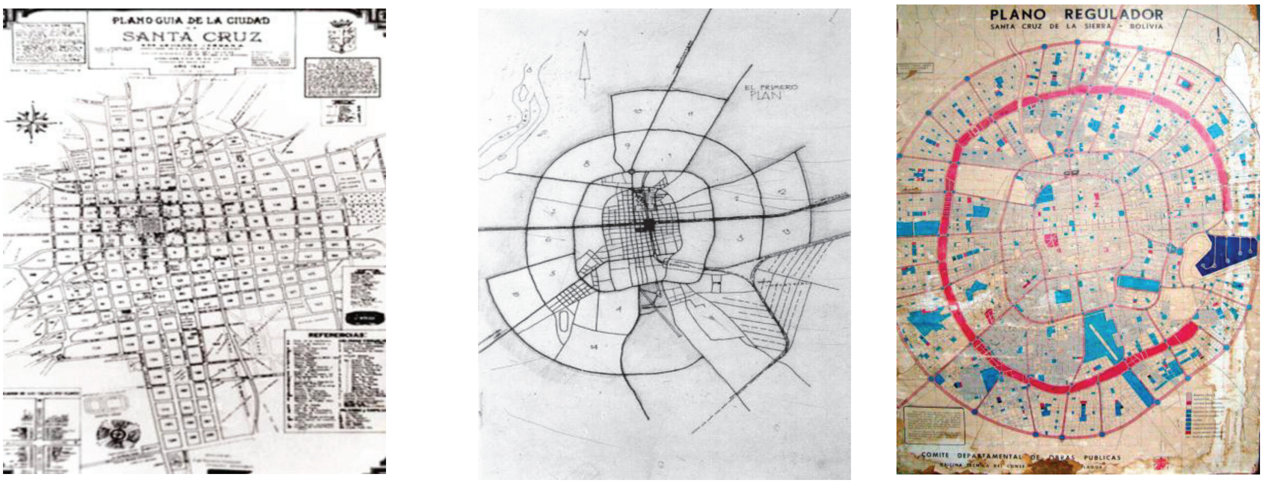


Figure 5 Santa Cruz 1948 – 1958 – 1970 - Local Government of Santa Cruz de la Sierra.

In the following years, the city began its development and the concern for a well urban development started a series of plans like the Techint Plan – 1958 (Figure 5), which proposes a radio - concentric city based on the new ideas of the “garden city” that has as its principal cell-unit the “unidad vecinal” for new expansions (15 units “Unidad Vecinal”). The “Unidad Vecinal” is mainly a residential land use in 60% of the area, complemented by some basic activities of recreation and primary services in the centre of the unit.

The new master plan was designed for 180.000 inhabitants that was estimated to be the population within the next 30 years of the city, considering a population density of 55 inhabitants/ha. with an occupancy rate of 35%. The urban norm of the plan established detached houses with porches.

However, by the census of 1976 (INE) the population of Santa Cruz increased to 374.605 inhabitants which exceeded the expected projections, so based on the Techint Plan and in order to respond to the growing population a new development strategy had been prepared that mainly repeated the radio-concentric design increasing the territory with residential areas using 47 more units of “Unidades Vecinales” and by keeping the spirit of the Plan Techint design through its urban regulations as rate densities, building norms and road networks. This new plan was called “Plan Director 1970” (Figure 5), that increased with 4.600 new hectares towards the urban area, defining special areas such as airport, industrial area and a mixed use area between the future new areas and the existing one (The Third ring). Eight years later as the city continued growing to a new extension of 14 hectares of land it had been planned with the same principles mentioned above and including a more zoned plan for all the city areas, to ensure the main principle design of the Techint plan approved in 1950’s but without considering the already emerging characteristics of the population growth and its strong economic activity.

In 1992, the National Census reports the city of Santa Cruz as the second largest city of Bolivia with 982.396 inhabitants, a situation that requires an extreme control over the urban development of the city, so again with a city bigger than was expected, a new Master Plan had been developed “Plano Director 1995” (Figure 6) that emphasised on the urban regulations and recommended to not extended the urban areas with the purpose of make a better use of the land. At this stage the index of occupation had increased with the aim of going along with the territorial policy, as the uncontrolled growth of the city changed the geometric design proposed from the beginning and it was already showing its own fast growing character.

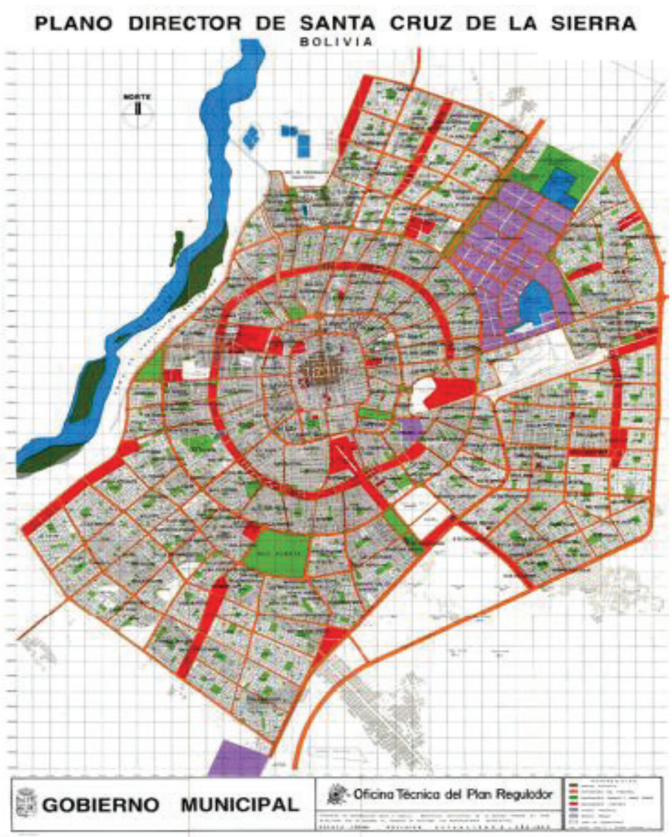


Figure 6 Plan Director Ampliado 1995 – Local Government of Santa Cruz de la Sierra

Subsequently as the development of the city followed by the same characteristics in the year 2003 a new plan has been presented, where the most relevant points in the area of urban development were:

- ✓ The delimitation of the Urban Area with 32.000 ha. within the next 15 years.
- ✓ The new zoning of the Urban Area to pursue a good urban equilibrium.

With the attempt made to rescue the identity of the city, the human scale and better living conditions as the actual situation of the city shows a fragmented territory. The expansion of the city that has increased the cost of the basic services, high costs of the urban processes, and reflecting the heterogeneity of the social and economic composition of the population due to the increased national migration and population growth. This new Plan is entitled “Plan de Ordenamiento Territorial” which is being implemented nowadays.

In conclusion: the city of Santa Cruz de la Sierra has had five Urban Masters Plans in its last 50 years in which all of them followed the same directions, every time allowing the use of more vacant land for the new developments leading to a fragmented city with lacks of basic services, bad public transport services or bad accessibility to basic services.

Considering the characteristics of the city as the mainstay of the economy of the country and its fast population growth, the expansion of the city will still be an issue that is expressed in the problems already mentioned so the alternative to develop scenarios based on the urban density for the city can be a helpful tool for the decision making in order to achieve a sustainable urban development for the study area.

5.2. General Description of the study area.-

Santa Cruz de la Sierra is located in the tropical part of Bolivia at the shores of the Piray River at 430 meters above sea level; it is a subtropical region. The city is well connected as it is shown in Figure 7, to the North by the highway that connects the department with the backbone of the country. The east is connected by roads to the Chiquitania and Cotoca counties which are planned as the backbone of the bio-oceanic route to Brazil. The west has the old road to Cochabamba that also connects to the valleys of the south, the Chaco and Argentina as it is shown in Figure 7.

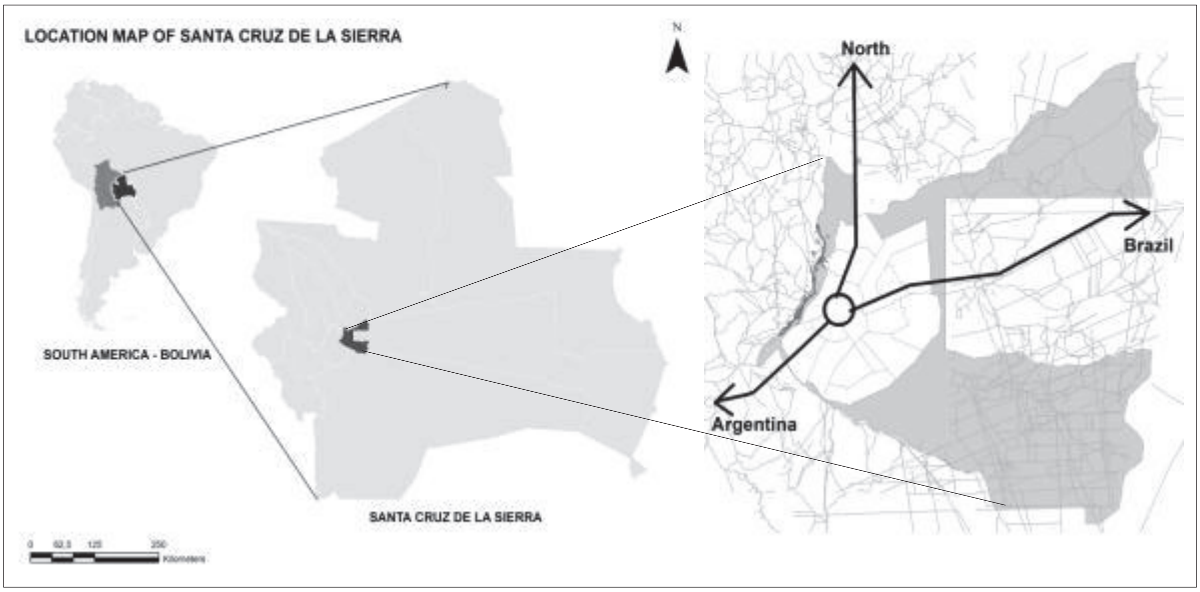


Figure 7 Study Area Location – Santa Cruz de la Sierra

(Own production base on data of the Local Government of Santa Cruz de la Sierra) .

Santa Cruz de la Sierra is the second largest city of Bolivia, which shows its important role in the development. Not only for the department of Santa Cruz but also for the entire country as being the centre of all the industrial and commercial operations. Its productive base is the agricultural activities that are mainly organised by private investments; where 96% of the labour sources are generated by private enterprises. These features have increased and have made the city a more attractive place to conduct business and living, reasons for which the population migration has increasing very rapidly over the last years.

5.3. Demographic characteristics.-

In the last census data in 2001, Bolivia had 8.2 million of inhabitants of which 24.5% were living in the department of Santa Cruz, placing it as the second most important city of the country. Santa Cruz de la Sierra is the most important city of the department of Santa Cruz as it has 72, 2% of the urban population, becoming the largest city in the department and the second largest city in Bolivia.

According to census data records of 2001show that the city has experienced a rapid population growth in the last 50 years with a population increase of 1.291.063 inhabitants, which can be seen in Table 11 below:

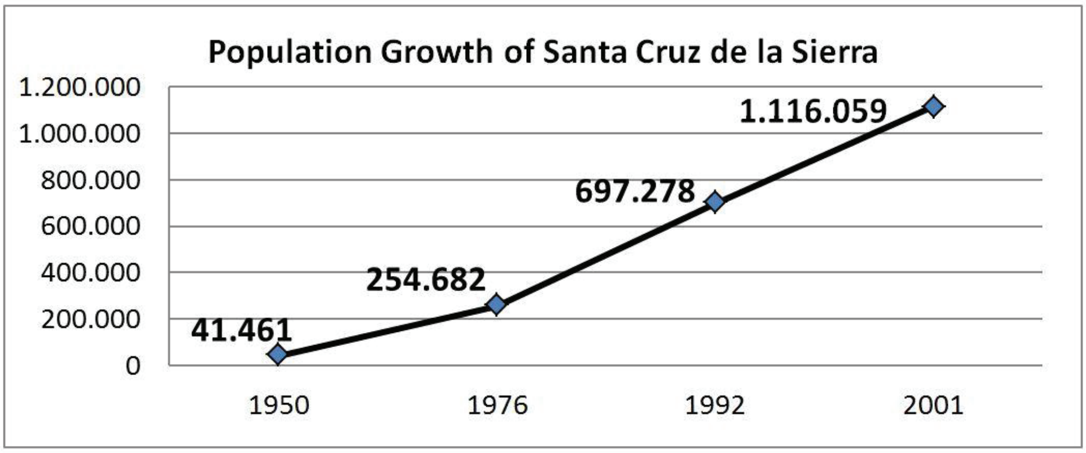


Table 11 Population Growth trend of Santa Cruz de la Sierra (Source: INE)

This rapid population growth that the city has experienced is caused by its own natural growth and an important influence of the migration from other parts of the country and neighbouring countries due to its important policies of rural land, its connections with the rest of the country by the new highway and its economic leaderships that made the city a good place for development and living.
By the census of 2001 the city had a growth rate of 5%, a value that has been on going from the last 50 years as the records of the census explains in table 12.

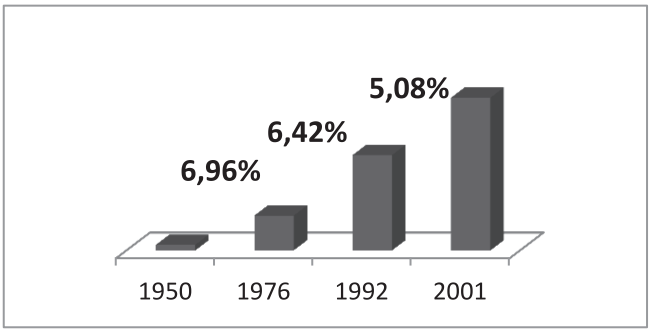


Table 12 Population Growth Rate of Santa Cruz de la Sierra (Source; INE)

5.4. Administrative Structure.-

The city of Santa Cruz de la Sierra, is the capital city of the Department of Santa Cruz and it is under the jurisdiction of the Local Government as the first section of the Department. The city is divided in twelve administrative districts called "*Distrito Municipal*" (municipality districts). Each of municipality districts have a basic cell unit named "*Unidad Vecinal*" (neighbourhood unit) which is the main element of the city for its design and development. The local Government is the most important public office in charge of the planning process of the city as well as for its implementation.

5.5. The urban norms of the study area.

The urban norm of the city of Santa Cruz de la Sierra is a set of norms that have a basic concept on the initial design idea of the city; which was a "Garden City". These norms have been applied since 1980 and its regulations are based on the zone of the city, the size of the plot, the width of the street and the typology of the emplacement chosen by the designer, which gives a big variety of densification and urban environment.

The city has been divided into five main zones which express one more time the concentric design that the city was following. In Figure 8 the zones of the city are mapped and it is clear to see how the core area of the city, actual downtown and CBD is the only that have more specific zones; the rest of the city is just one big zone. For each zone there is an index IA "*Indice de ocupación*"(Index of occupancy) in m2 available that varies according to the plot size and wide of the street as it was mentioned before.

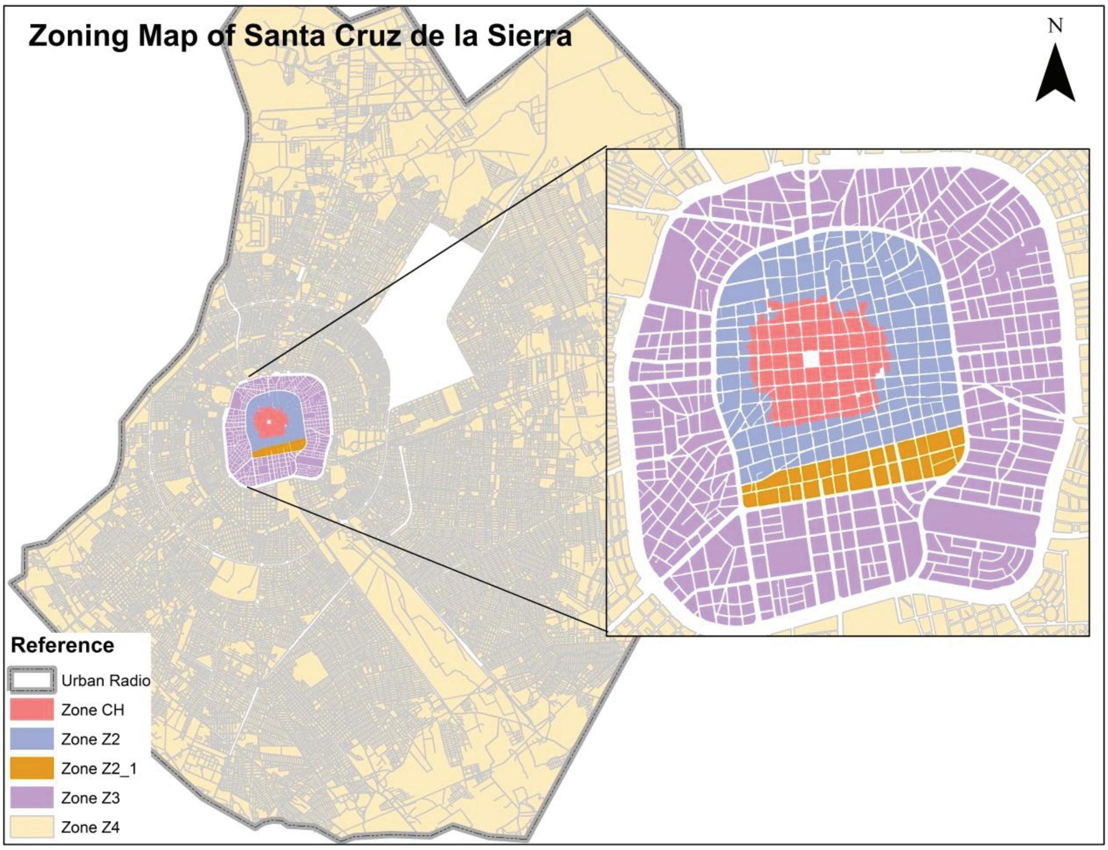


Figure 8 Zoning Map of the Study Area

(Own production base on data of the Local Government of Santa Cruz de la Sierra) .

Following, Table 13, there is a description of all the urban rules according to each zone, from where the IA (index of occupancy) is defined according to the design of the project, because the retreat of the building in a plot varies depending the function of the room that is settled in a specific area. Also we can see that the height of the buildings in most of the areas depends on the IA (index of occupancy) and other sectors that have an established limit.

Zone	Width Road	IA (occupancy index)	Height Allowed
CH (Historic Centre)	According to the classification of the buildings		12.50 meters(in some areas)
Z2	All roads except close roads and	4m2/m2	Defined by the IA and the design of the project.
Z2_1		4m2/m2	Defined by the IA and the design of the project.
Z3	Roads with less than 16 m. of wide	2.5m2/m2	30 meters
	Plots on Primary roads or with more than 25 m of wide	4m2/m2	Defined by the IA and the design of the project.
	Road less than 16 m. of wide	According to the height allowed.	12,50 m
	Between the 2nd and 4th ring of the city in the *"colectoras"* connections road inside a neighbourhood unit	2.5m2/m2	30 m
Z4	Plots on Primary roads or with more than 25 m of wide	4m2/m2	Defined by the IA and the design of the project.
	Outside of the 6th ring on primary roads	6m2/m2	Defined by the IA and the design of the project.
	Outside the 4th ring of the city in the *"colectoras"* connections road inside a neighbourhood unit	According to the height allowed	9,50 m

Table 13 Index of Occupancy and Height for the urban zones of the study area.

5.5.1. Typology of the buildings

According to the urban regulations of the city of Santa Cruz de la Sierra, there are three types of typologies for buildings in the whole city, where according to the zone where it belongs other urban norms must be applied also. These policies had the objective to regulate the urban density of the city as well as the right use of the land as its stands in the *"Codigo de Urbanismo y Obras" (*Urban Code Norm)(Goverment, 1980) . The three typologies are explained bellow in Figure 9 and a description of each of them is made in order to understand what the index of occupancy and build form of the city could be.

Type A. - Tower without any basement that can be developed in any urban zone of the city, the height depends on the retreats according to the type of spaces located in the design of the building. It is a single block in the middle of a usual plot.

Type B .- Basement without a tower that can have more than one floor according to the IA (Occupancy Index) sets for the specific plot size and the urban zone to which it belongs. The retreats also will be according to the type of spaces located in the design of the building. The height will be determined by the urban zone where it belongs.

Type C. - Tower with basement, it is allowed to have more than one tower in one basement that also can have more than one floor according to the height limit of each urban area. The retreats of the tower are according to the type of spaces located in the design of the building.

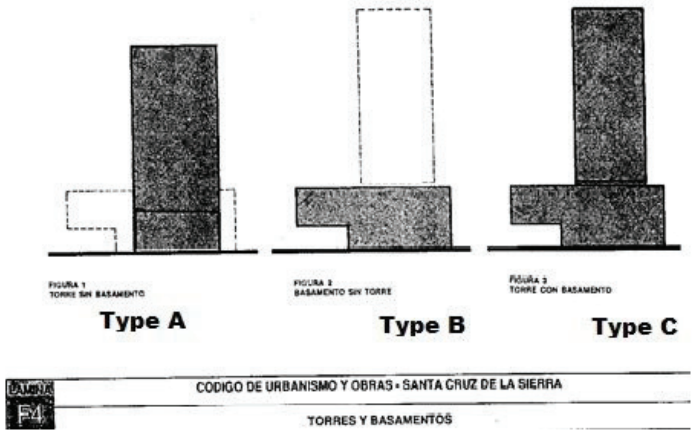


Figure 9 Typologies of Buildings from Urban Code Norm (Goverment, 1980).

5.5.2. Identification of areas with new developments and typologies

Santa Cruz de la Sierra due to its high population growing , its immigration from the rest of the country and its strong economic development has been experiencing a change in the usual residential buildings typology, so far there are areas that keeps the traditional typology of a single family house and there are areas where the multifamily buildings with a specific typology such as tower without basement are taken place, so the developer can get more floor areas built up and more family units positioned in the market as Figure 10 shows. These urban zones have been developing multifamily buildings based on the zone regulations of the urban code. Following there are some captions from the image satellite to show how these developments have been increased.

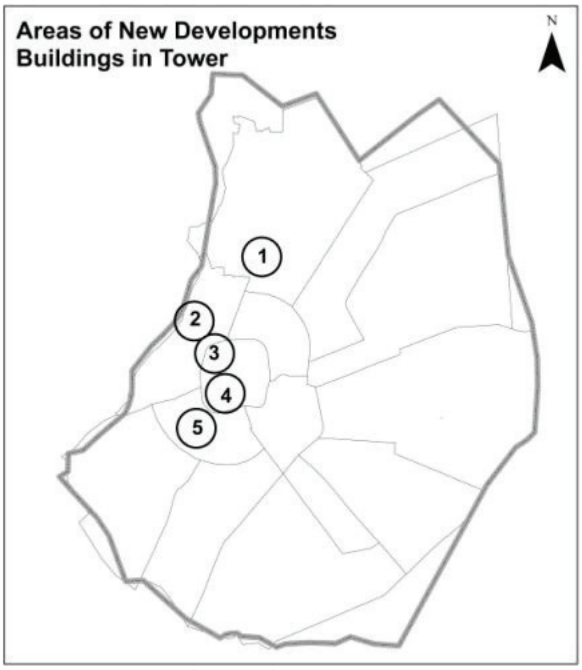
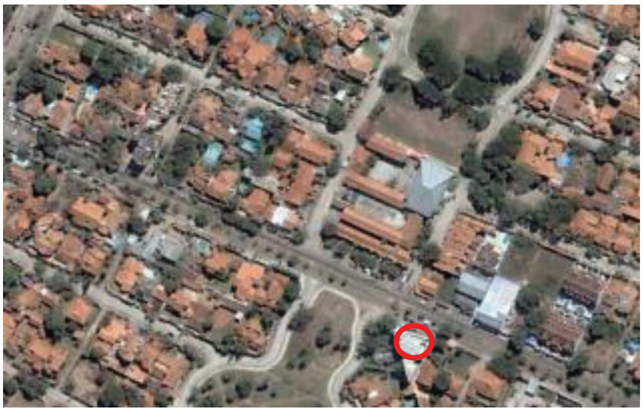


Figure 10 Areas of New Developments

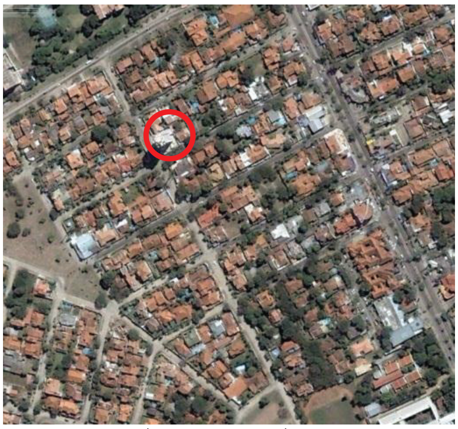
Zone 1. - North area of the city.



Av. Los Cusis / Year 2006 / 1 Tower Building

Av. Los Cusis /Year 2011/6 Tower Buildings

Zone 2. - North West area of the city.



Colector Avenue/ Year 2005/ 1 Tower Building

Colector Avenue / Year 2011/ 4 Tower Buildings

Zone 3. – North CBD area, close to downtown.

Libertad St. /Year 2006/5 Tower Buildings

Libertad St./Year 2011 / 10 Tower Buildings

Zone 4. – South CBD area, close to downtown

Av. Alameda Potosi/ Year 2006/4 Tower Building

Av. Alameda Potosi/ Year 2011/8 Tower Building

Zone 5. – South area of the city.

Colector Avenue/ Year 2005/ 0 Tower Building

Colector Avenue / Year 2011/ 4 Tower Buildings

All the sectors that have been presented are residential areas, with a medium high economic level, whom are willing to live in these type of building in order to stay closer to the CBD and gain more security. Figure 11 shows examples of these typologies.

Figure 11 Examples of Tower Buildings in Study Area

5.6. Physical structure .-

The city of Santa Cruz de la Sierra has an extension of 139.178,69 ha. and the study area is mainly concentrated in the urban zone which comprises 27% of the territory. It has 15% of protected areas and three unconnected rural zones which completes the total of land of the city. This land use classification is based on the *"Plan de Ordenamiento Territorial"* (Strategic Territorial Plan) for 2020(Goverment, 2005), which was established by the local government in 2005. Figure 12 shows the spatial distribution of the land use.

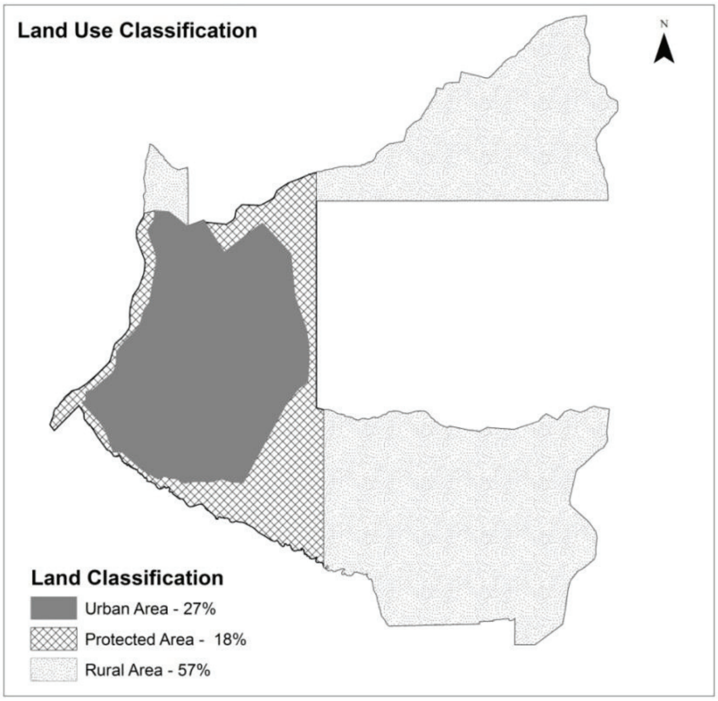


Figure 12 Land Use Classification of the Study Area.

(Own production base on data of the Local Government of Santa Cruz de la Sierra) .

The urban area has an extension of 38.487, 91ha. that has been established by the last planning policy of the city approved in 2005. This urban radio has to attend the land demand for the next 15 years. The urban area is characterized by its zoned plan, based on its origins of the Plan Techint design which was originally designed as a garden city in the early 50's and for which it was expected to have 350.000 inhabitants by this time. This zoning plan was adapted in the 80's trying to respond to the rapid development of the city. Nowadays these norms are still the same and do not express the leader active economy and development of the city.

The urban area has two main classes: the urbanized area, which consists in the already existing city and projects that are in development at this time. The area to be developed containing the spaces that are not occupied within the urban radio, are classified into three sectors: Immediate area of urbanization (ZUI), Delayed area of urbanization (ZUD) and developable area of reserve (ZUR). According to the norm in these entire three sectors the urbanization process is allowed if the project ensures the provision of basic services, sewage and roads networks that has driven the city to the current expansion.

The already urbanized area named as "Urbanized Area" has also a classification that assigns a specific use for each part of the city, which has regulation for subdivision of the land, disposition and volume of the building. These zones are named and described below.

5.7. Basic Design of the study area .-

The radio concentric design of the city implemented by the Techint project introduces a change in the traditional grid design of colonized cities. It introduces a vial structure that has two main elements in this primary road system: the *"anillos"* ring roads that are the connector roads around the city, which has the function to distribute people around the city and the *"radiales"* which takes the people from the CBD to the residential areas outside the city. These primary road structure have an important role in the urban norm as it is where the more high buildings are allowed and where the IA (index of occupancy) can also be higher than in the other areas of the city. Figure 13 shows the basic road design of the city and the basic cell unit of design.

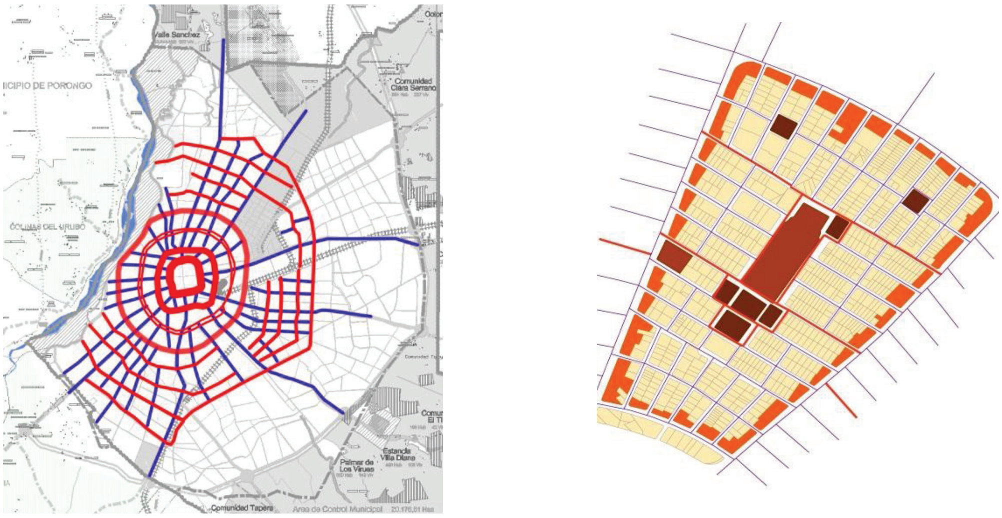


Figure 13 Structure of the Primary road and basic cell unit of the city. (Goverment, 2005)

The other basic element of the city design is the *"Unidad Vecinal" Neighbourhood* Unit, which has a basic design where the central area of the unit must have the primary equipment for the rest of the area that is the residential part. Also it has some roads that are called the *"colectoras"* Collectors that are wider than the rest and where the m2 and the heights of the buildings are different than the rest of the unit. In the actual situation of the city, these design regulations have been follow in the central part of the city as the image A shows and the more popular and informal expansion in some areas did not follow them like the image B in the Figure 14.

So the city mainly in the central area until the 4th ring keeps a very strict design which is the oldest part of the city as well as, in the outside these limit and especially in the periphery the development loses these characteristics and just grows in an informal and more natural way.

Figure 14 Image of basic cell unit of the city.

5.8. Land Use Distribution in the Urban Area

The Urban area of the city of Santa Cruz de la Sierra has a different land use distribution according to its urban norms. Figure 15 shows the land use distribution of the city in the year 2008 where it can be seen that the main area of the city has a residential use and the rest of the use is distributed along some main roads. It also presents how the city has already occupied most of the urban radio that is supposed to hold for the land demand until 2020.

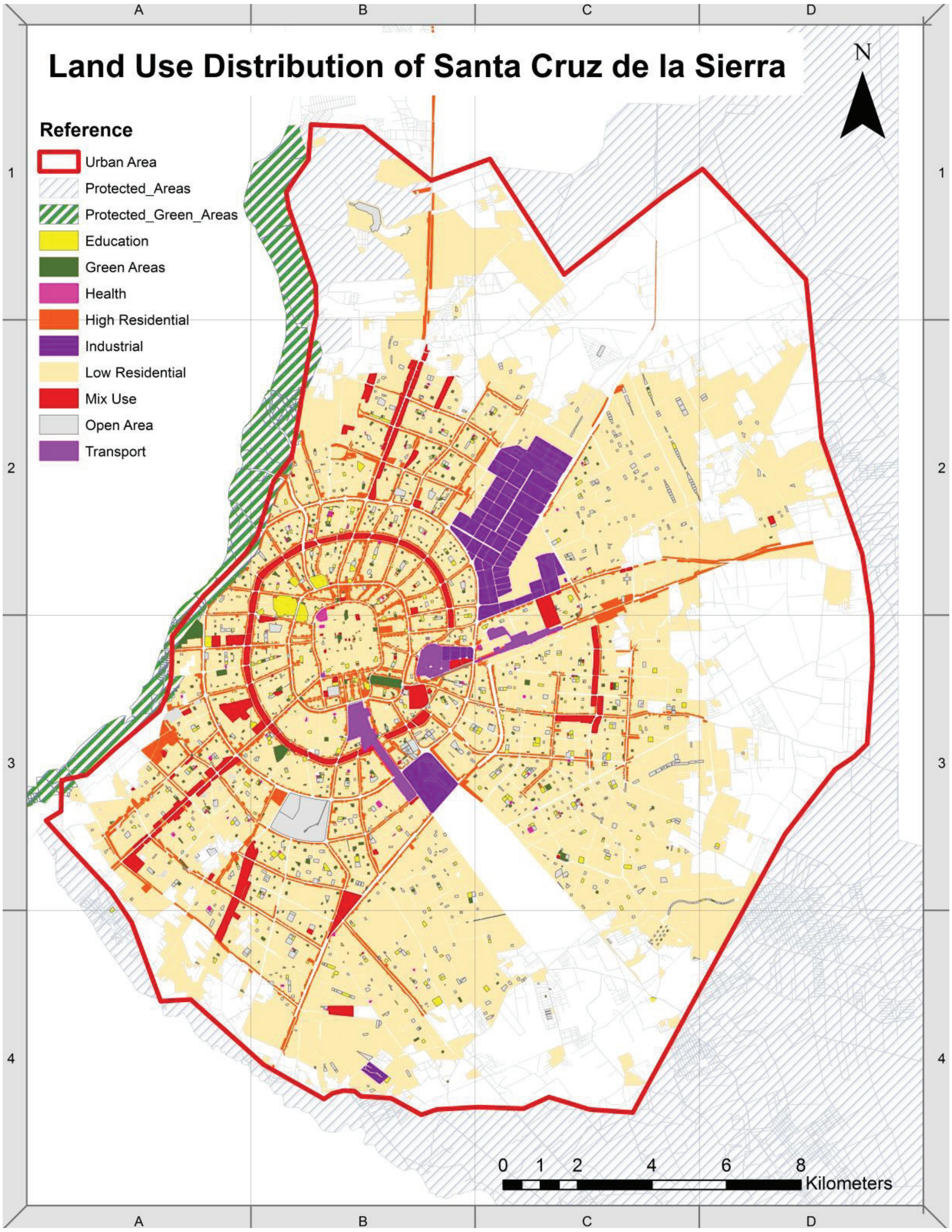


Figure 15 Land Use Distribution of the study area

(Own production base on data of the Local Government of Santa Cruz de la Sierra) .

The relation between the land use distribution of the urban area is a reflection of the urban norm that has established where the urban area must have a 65% of residential use and the rest for use of public areas and streets. Table 14 shows the actual percentages of this distribution, and illustrates how the other 35% is distributed in different uses. In Figure 15 it can also be seen that the different uses are spatially located along some main roads and in the core of the central area while the residential use is distributed among the whole territory even where there are no other uses that can provide services to those areas.
Figure 17(section 2C – 2D, 3C-3D and 4B of the map).

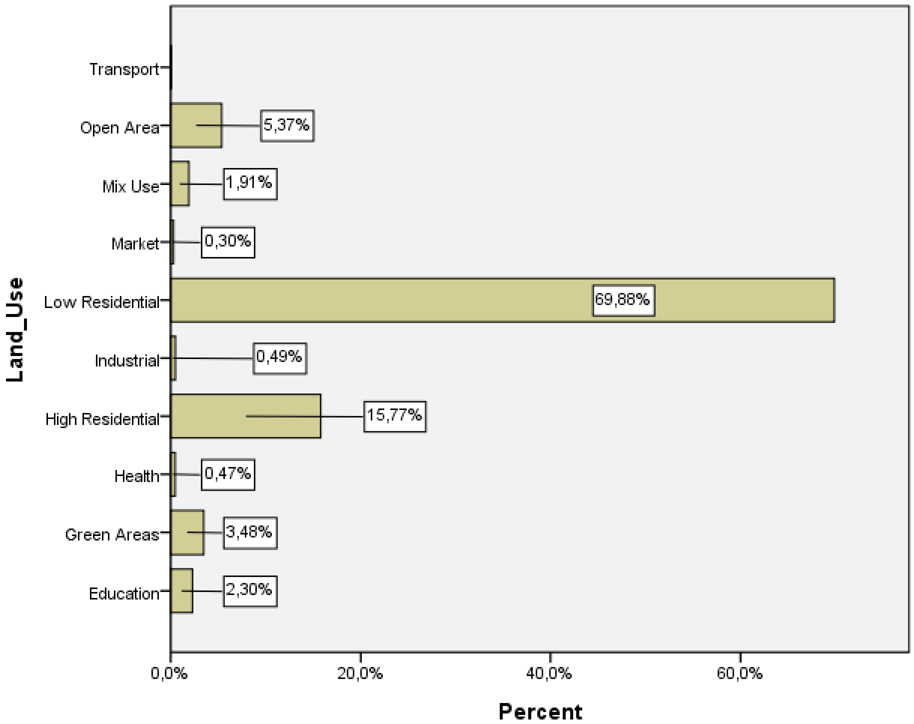


Table 14 Land Use Distribution

5.9. Urban Density of the City

Based on the data of the *"Plan de Ordenamiento Territorial"* (Strategic Territorial Plan)2005(Goverment, 2005) and the census data of 2001, Santa Cruz de la Sierra has shown a low urban density index compared to the statistics of reports such as Demographic World Urban Areas(Cox, 2007) ,World Cities Web page and City Major Statistics(Foundation, 2012) ,where the average of inhabitants per Km2 is 5.66. This data comes from the largest 125 cities of the world ranked by its population density. The average urban density of the study area is 65 inhabitants per hectare which is 0.68 inhabitants per km2.

The spatial distribution of the urban density of the study area in Figure 16, illustrates how the 1.700.000 inhabitants are spread around the territory. The densest areas are in section: B2 which is part of the "Lazareto" neighbourhood near the central area. The sections B3 and C3 are characterized by its lower class with very popular neighbourhoods that were part of a national housing plan in 1980.These areas had an increase of its population because many immigrants from other parts of the country came to live there. The rest of the territory has an almost even distribution.

Figure 16 Urban Net density of the Study Area
(Own production base on data of the Local Government of Santa Cruz de la Sierra) .

5.9.1. Urban Net Density of the City

The urban net density is calculated by inhabitants/m2. of the residential areas of the city In Figure 18 it is easy to see how the city has no limits to expand its urban growth and the average of the net density responds to the urban norms that the city has defined in the 1980's and that are explained in section 5.5 of this chapter.

The spatial distribution of the net density or built up areas has no pattern because it depends on the size of the plot, the zone and the urban norm. An example is the two sections of the satellite image from the study area, Figure 17 that identifies two different patterns of design in the city.

Figure 17 Image areas with most net density.

Figure 18 Urban Net Density of the Study Area

(Own production base on data of the Local Government of Santa Cruz de la Sierra) .

6. SETTING UP THE MODEL

This chapter discusses the basics of the scenario approach and the different considerations and assumptions for the implementation of the model.

6.1. Selection of the approach to develop the scenarios.

Through the literature review of the scenario development in chapter 2, section 2.4.3, each paper revises a different approach and it does not define a clear criteria for the selection of this step, there are many common elements mentioned in each method and all of them are considered relevant.

In order to define the most adequate approach for the development of the scenarios for this research a distinction can be made according to three main areas that are mentioned in the chapter 6 of Scenario Development of the Geo – Resource Book (Jäger, et al., 2008):

- ✓ The Project goal that helps to raise awareness and to motivate to new ideas.
- ✓ The Process design that refers to the scope and the details of the analysis, amount of quantitative and qualitative data used definition of stakeholders, expert knowledge and type of research.
- ✓ The scenario content that defines the variables and dynamics of the scenarios and how they interconnect.

Although there are other criteria that should be considered in the selection of the approach to develop the scenarios that are basic elements of any of the main areas mentioned above. The work of Vitriani (Vitriani, 2010) discuss these elements from which the author also consider relevant for any approach selection and for the development of the present research.

1. The participation of the stakeholders is considered very important as the construction of the different scenarios is based on the stakeholders' interviews that are the main guidelines for the future plausible states of the study area and also to analyse the impacts of the policies of urban density in the study area.

2. The definition of the scenario approach in a qualitative or quantitative process, both categories have their advantages and disadvantages as the literature explains: Qualitative Scenarios has as advantages of been understandable, represents the views and interest of many areas. The disadvantages are that they are arbitrary, difficult to test the assumptions and do not provide numerical information. Quantitative Scenarios are model based, containing numerical information and the assumptions are clearly identified while their disadvantages are that they can be confusing, they cannot present all the extent of the vision and they cannot feature values or lifestyles.(Jäger, et al., 2008).

3. The applicability of the approach that must be according to the study area, the scope of the analysis, the objective and specific analysis that will be done.

6.2. Approach definition for the present research.

Based on the literature review that presents many approaches with almost similar elements and common steps in all the processes, a combined structure is designed to develop the scenarios for this study that is based on the framework of an IEA presented in the Geo Resource Book(Jäger, et al., 2008) ,the paper of Plata –Rocha (Plata-Rocha, et al., 2011) and the objectives of the research to analyse the impacts of existing policies in the future development of the city of Santa Cruz de la Sierra; how a particular scenario will unfold.
The defined structure for the scenario approach is presented in the following Figure 19.

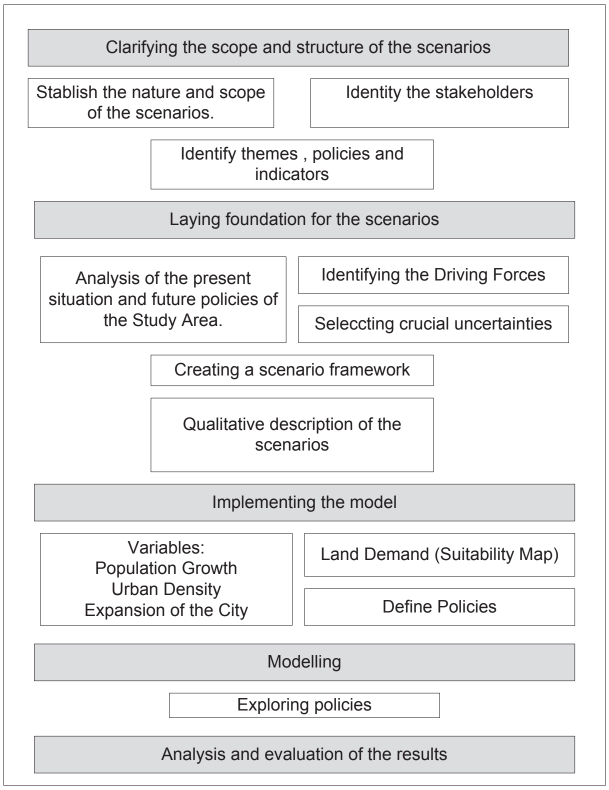


Figure 19 Structure for the scenario development

6.3. Clarifying the scope and structure of the scenarios

Scenario development for this research integrates qualitative and quantitative processes along with the stakeholders' participation, which contributes to the definition and evaluation of the different states of the future for the study area.

The existing urban plans for the city of Santa Cruz de la Sierra, predict that in the next 20 years the city will duplicate its already urbanized area, which will exceed the already established urban radio, with a city with more than 3.000.000 inhabitants and a very low density (less than 60 inhabitants per hectare) within this context the cost for provision of the basic services, basic equipment and urban infrastructure will be too high. *PDM-Plan de Desarrollo Municipal 2009-2015* (Municipal Urban Plan2009-2015)(Sierra, 2009).

Base on this context the scenario scope is a study of the future plausible scenarios of the city of Santa Cruz de la Sierra addressing the expansion of the city, the urban norm of the density and considering the existing urban policies.

The time scope of the study will be 14 years considering the base line year 2009 that is when the *PDM-Plan de Desarrollo Municipal 2009-2015* (Municipal Urban Plan2009-2015) report is presented, this is according to the national regulations of the country that states that an urban plan must be review every 5 years and considering the fast growing of the city 14 years will be a good period for the study.

The stakeholders involved for the development of this research were from a variety of backgrounds, in chapter 4 it is a clear description of each group and its relation with the development of the city. The interviews done with each stakeholder helped to develop the main vision and the narratives of the different scenarios. For this research the author defined the two most extremes situations for developing the scenarios.

Themes and policies are identified based on the *PDM-Plan de Desarrollo Municipal 2009-2015* (Municipal Urban Plan2009-201) (Sierra, 2009) where a list of 9 main problems of the city of Santa Cruz de la Sierra are identified as important ones that need to be solved. The author selected two from the main problems that are related to the territorial space and the urban development of the city, founded on the concerning of the space consumption that the actual development of the study area has according to its the urban norms.

"The other, what is happening in Santa Cruz de la Sierra is the urban growth and nothing else, which is characterized solely by the expansion of the urban chaos. We are confused to the point where we no longer seem alarming these new developments within 20 kilometers of the fourth ring, nowhere near where the city will never reach with economic resources in the next 50 years to provide them with paved roads, schools and colleges, health posts, hospitals and, even more dramatic in relation to household income, sources of work in those neighborhoods….. "
El Deber, Santa Cruz de la Sierra –Bolivia, 2009

"In Santa Cruz we still lack of comprehensive approaches in urban development planning. We anchored in schemes that do not take into account in a projected future, all the factors, elements and aspects inherent of the physical expansion of a city like ours. We are still unable to reconcile criteria parameters which secure the further development of the city. Some are in favor of regulation in favor of greater concentration of population in what is urban sprawl. They believe that in this way would be less expensive the cost of basic infrastructure and roads in the city. "
El Deber, Santa Cruz de la Sierra –Bolivia, 2010

The main problems to be addressed in this research based on The *PDM-Plan de Desarrollo Municipal 2009-2015* (Municipal Urban Plan2009-2015)(Sierra, 2009) are:

1. Physical Space Dimension. - This refers to construction delays of the basic infrastructure and equipment due to the fast expansion of the city.
2. Territorial Dimension. - The model of the city has been broken and now shows a fragmented city very dispersed with very low densities and without respecting any natural areas.

The policies considered for the scenario development are the ones that are related to the urban density already described in Chapter 5, from the actual urban code of the study area. The indicators where identified according the results of the activity realized on fieldwork as it were explained in Chapter 4.

6.4. Scenarios definition.-

After the development of the matrix of new ideas obtained from the interviews of the stakeholders, some common elements were found between different groups, as well as some differences of opinions between peers of the same group due to the diversity of the stakeholders. These differences of results force to establish two extreme visions of the city of Santa Cruz de la Sierra for the next 14 years in order to follow the criteria of a good scenario defined by (Xiangô & Clarke, 2003) "a good scenario creates surprising and plausible futures…".

As a result the author defined two scenarios that will help to understand the possible effects of the actual urban norms of the city and the new ones suggested that were obtained by the analysis of the data. Table 15 and 16 shows the main policies of each scenario.

SCENARIO 1	
Growth of the city	No more expansion. The vacant land must be preserved with incentives to not urbanize further. Save and keep the little rural land left, available for its own purpose. Stimulate centralities in different areas of the city.
Land Use norms	Around the centralities identified, allow a mixed land use. Inside the Unidad Vecinal unit also allow a mixed land use.
Urban Density : FAR	For the mixed use the density must increase. Higher Buildings Residential building use can also increase until four floors.
Net Density	Increase with four floors to most all the buildings.

Table 15 Strategies of Scenario 1

SCENARIO 2	
Growth of the city	The city must grow as a metropolitan area now, with a growth until the urban limit. Stimulate centralities in different areas of the city. Save and keep the natural areas free. Rescue open spaces.
Land Use norms	Around the centralities identified, allow a mixed land use. Inside the Unidad Vecinal unit also allow a mixed land use.
Urban Density : FAR	Increase the density of the main roads. For the mixed use the density must increase. Higher Buildings
Net Density	Keep the actual norm established.

Table 16 Strategies of Scenario 2

6.5. Laying foundation for the scenarios.-

At this stage the definition of how many scenarios will be developed and what should be the essential distinctions among them (Jäger, et al., 2008) are made. For this research the main driver considered is the population growth as the element for the land demand, according to the trends of the population growth of the study area, this rate is 5,2 % which situates the city in the 14th position among the cities with the most highest population growth rate of the world. (Foundation, 2012).

The critical uncertainties on the population growth are:

1. The urban growth rate is the same during the 14 years of analysis.

This is part of the scenario framework, as the population growths the demand for new urban land will increase which must be developed according to the urban norms stabilised. Among to this one variable is identified that is the different policy options of the urban density for the scenarios.

The framework is completed with the analysis of the actual situation of the study area and the different trends recognized in the analysis of chapter 5.

Then the scenarios are summarized as:

A. **Compact growth scenario .-** Identified as a "compact city" where almost all the new development must be in the already urban built up area, increasing the urban density in the areas that are already identified in the analysis, and where the actual urban norm allows the increase of the density. These also will be accompanied by the development of the new centralities that the Plot – *Plan de Ordenamiento Territorial* (Territorial Master Plan) (Goverment, 2005) has recognized . This compact growth scenario adopts the following policies for the new development areas:

   - ✓ New developments must be in the special areas identified by the Plot – *Plan de Ordenamiento Territorial* (Territorial Master Plan)(Goverment, 2005).
   - ✓ Areas with high densities must have incentives for more developments as well as in the areas close to the primary road.
   - ✓

B. **Sprawl Scenario .-** In the Sprawl scenario, the development of the city continuous first with the new land to urbanized and the later if the demand stills will be the densification of areas where the density can be higher, this means that the city will keep on growing until reaches its territorial limits. The policies adopted for this scenario are:

   - ✓ New developments can be settled in the vacant land.
   - ✓ Also the areas identified by the Plot – *Plan de Ordenamiento Territorial* (Territorial Master Plan)(Goverment, 2005) are available for new developments.

6.6. Implementing the model.-

For the implementation of the model some steps have to be made, such as the projection of the population growth, demand of the land according to the new population and definition of the scale of the analysis.

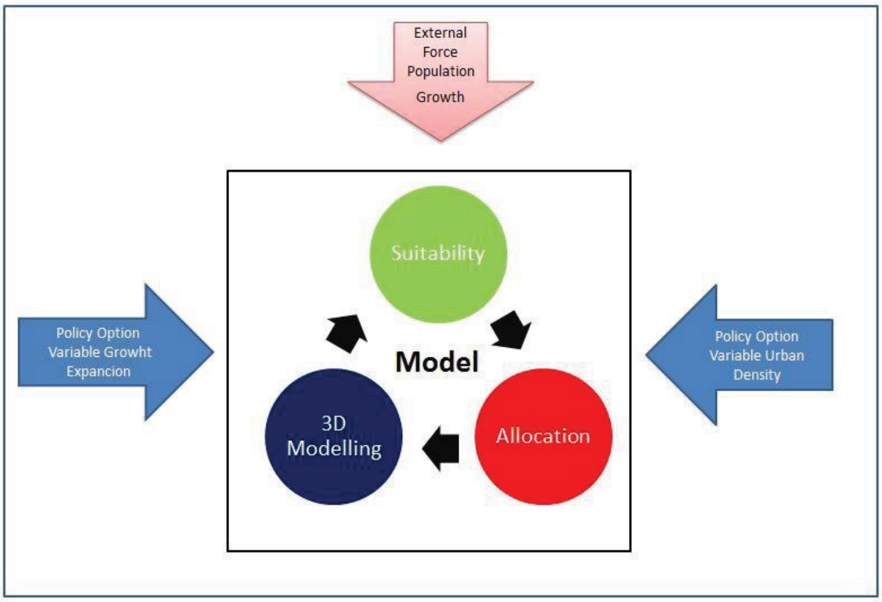


Figure 20 Model Diagram

6.6.1. Projection of the population growth and land demand.-

The population growth was calculated with the geometric method assuming that the economic and normal trend of the context will not change like it has been in the past 50 years; having a constant growth rate. The increment will change each year as the calculations were made yearly. The data used is from the National Institute of Statistics (INE) the same that was used for the two urban plans mentioned before. The population growth rate is 5, 2 % that considers also the population migration that have been an important factor for the fast growing of the city. This growth rate is according to the last census data of 2001.
The formula used for the calculation is:

$$Pn = P0\ (1 + r)n$$

Where:

Pn = Population at the end.
P0 = Initial Population.
n = number of intervals between Pn and P0
r = annual growth rate.

The housing demand was calculated based on the the assumption of the population growth as the main driving force of the model divided by the parameters set by the census data that establish 5 persons as the family size unit. Table 17 shows the trend of the housing demand during the different years.

Year	2001	2009	2015	2020	2025
Total Population	1.545.648	2.318.657	3.142.903	5.217.811	5.217.811
Housing Demand (units)	309.130	463.731	628.581	809.915	1043.562

Table 17 Housing Demand

The future land demand considered in the model is for residential development and is determined based on the urban norms(Goverment, 1980) of the city that establish a minimum size for a family unit; shown in Table 18. For the research the type of family unit considered is number three that has 160 mts2, as the census data sets 5 persons for the family size.

Type	Number of rooms (dorms)	Total of M2
1	1 dorm	100 mts2
2	2 dorm	140mts2
3	**3 dorm**	**160 mts2**

Table 18 Basic Family Unit

The land demand in Table 19 was calculated multiplying the amount of residential units needed multiplied by the basic size of the family unit defined in Table 18. The land demand is in squares meters, because all the norms that refer to the density and buildup of the city of Santa Cruz de la Sierra are based on this measurement unit.

Year	2009	2015	2020	2025
Total Population	2.318.657	3.142.903	5.217.811	5.217.811
Housing Demand (units)	463.731	628.581	809.915	1043.562
Land Demand (Mts2)	74.197.025,16	100.572.890,49	129.586.461,50	166.969.955,04

Table 19 Population Projections and Housing demand.

6.6.2. Scale of the model.-

The research area is the urban area of the city of Santa Cruz de la Sierra, that has stabilised by the last Master Plan of the City in the Plot – *Plan de Ordenamiento Territorial* (Territorial Master Plan)(Goverment, 2005), the unit for the analysis is the block that the author considers most appropriated after the analysis of the urban norms in chapter 5 that concludes that the main area of the city has the same urban norms with the only variation of the height and the Index of Occupancy (IA) explained in Table 10 of chapter 5, so it can be then generalized in the block for this research.

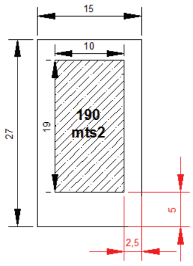
6.6.3. Principal considerations of the model for the Allocation analysis.-

1. The urban norm of the city defines an Index of Occupancy (IA) and a Height for different areas of the city, five are the areas from which four of them are located in the CBD and main roads, and the rest of the city has the same zone and norm. This is a conclusion from the analysis of the section 5.5 for chapter 5. This situation allows working with the block unit in the model defining the same urban norm for the entire block and for each block of the city.

2. The research is based on residential use then the urban norm (Goverment, 1980) is applied deducting the 35% of the total area of each polygon that is vacant as the urban norm specifies. This percentage of area is for public spaces and roads.

   Shape Area (mts2) **in vacant areas** – 35% of the total Shape Area (mts2) = Residential Area for new developments.

3. In the urban area and vacant land (after the 35% deducted from point 2 above), a 40% of the rest of the area is discounted as the retreats that the building must have according to the design of the building and the urban norm for each space (room) of the design(Goverment, 1980). Considering the size of the plot and the minimum retreats that a design can have as it is shown in Figure 21 the percentage left for the build-up area is 60% of the plot area. This value is discounted for each block of the model in order to achieve its maximum capacity.



The area of the plot is 405 mts2
The remaining area after the discount of the retreats is 190 mts2.

Figure 21 Plot Areas

4. For the urban area that is already build up the author assumes an existing area of 320m2 based on the criteria that the city has in its majority of the territory the urban zone Z4 – that allows an increase of 2m2 /m2 and that the typology of the residential units are two floor considering that the family unit size adopted by the model is 160 mts2. This built up area has been identified with the satellite image of the base line year 2009 and the dataset of the Local Government with the plots that are urbanized for each plot in the build-up area for the allocation analysis.

All these consideration gives the maximum capacity of the block to allocate the new land demand projected for each scenario.

6.6.4. Principal considerations of the model for the maximum urban density 3d model.-

1. The number of plots (parcels) calculated for each block is based on the assumption of the average size of a plot (parcel) considering that the city has a basic design cell unit (neighbourhood) explained in chapter 5, from where the number of plots (parcels) is calculated based on the average size that a plot has in the design of the city : 360 mts2 in most of the residential areas, then :

   Block Area (m2) divided by the size of the plot assumed (360 mts2) =
   # Number of plots in each block.

2. For the number of family units that each block has the maximum capacity of the block used for the allocation analysis is divided by the family size unit 160mts2 used for the calculation of the land demand.

These considerations allow building the 3d model of the city for each scenario, observing the maximum capacity of mts2 and height of each plot.

6.7. Limitations and recommendations of the model.-

There are many other factors that could be included in the model such as the variable of the population growth due to the economic situation of the city, or the analysis of the different typologies of family units according to the socio-economic status, or new policies about the land use distribution that will have an impact on the outputs of the land allocation and densification. Also the identification of special natural areas in the vacant land or consolidate urban area for its protections. All these were not able to implement due to the lack of information and time constraint.

For the implementation of the model many simplifications have to be done to make it operational especially in the calculation of the 3d model, assuming that all the buildings will be with the same design because the urban norm of the city is very flexible according to the design of the project.

6.8. Calculation of the maximum urban density for each block (3d model).-

For the calculation of the maximum urban density of each block the urban norm was applied and also the considerations of section 6.6.4.

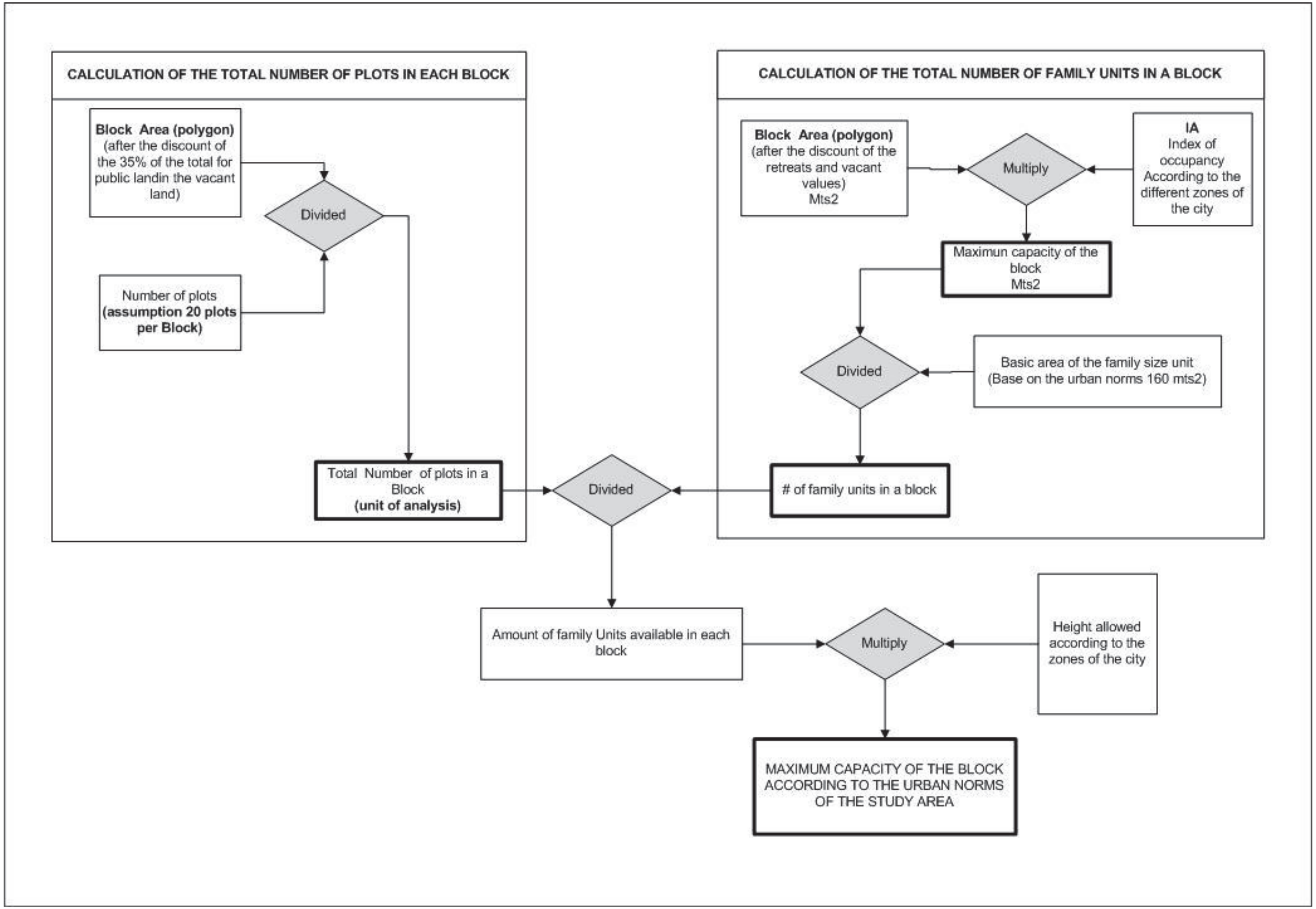


Figure 22 Diagram of calculation of maximum urban density of each block (3d model)

The calculation for the maximum urban density for each block of the city showed in Figure 22 has three main steps:

1. The calculation of the total number of plots is the total area of the shape divided by area (360mts2) assumed as the average size of the plots. Here attention has to be paid to the new vacant land that is allocated by the model because for the new land the urban norm states that 35% of the land has to be used for public services, which refers to streets, green areas and other activities for public service. (Section 6.6.3). The result is the number of plots that each block will have.

2. The calculation of the total number of family units in a block is according to the maximum capacity calculated in the previous process for the allocation land is the total area of the block (after all the respective discounts for urbanized areas) multiply by the IA Index of occupancy that is established by the urban norm of the city and is analysed in chapter 5, section 5.5. (Table 13) from this calculation the maximum capacity of build-up area is obtained, then this is divided by the basic family area assumed by the author , that in this case is 160 mts, defined in section 6.6.1.The result from this operation gives the number of family units of each block according to its maximum capacity and the urban norm.

3. Following the two results obtained in step 1 and 2 are divided in order to achieve the amount of family units that are able to be in each plot.

4. This result is multiplied by the height of the buildings that the author assumes to be 3 meters for each floor and revised with the height allowed by the urban norm of the city.

5. Obtaining at the end a build-up block that represents the plausible urban context of the city in the different scenarios according to the policies implemented in the suitability map and allocation land processes.

7. MODELLING THE SCENARIOS

This chapter presents the different stages of the modelling and their outputs, discussing how they were accomplished them.

7.1. Suitability Analysis.-

The suitability analysis was done to identify the potentials areas of the city and to estimate the amount and location of the future developments according to the visions defined for the different scenarios. The base layer for this analysis is created as a result of the analysis of the actual situation of the city done in chapter 5. Table 20 shows the elements considered in the base layer for the suitability analysis.

Element (field)	**Definition**
Shape Area	Mts2.
Land Use	Residential.
Zone	Identification of each polygon (feature) with an urban zone code.

Table 20 Elements of the base layer for the suitability analysis

The constraints identified for the suitability analysis are all the areas that are not residential such as equipment areas, green areas, industrial areas that are identified in the analysis of the situation of the city and placed in a different layer.

The criteria used for the suitability analysis are identified based on the visions of the two scenarios defined according to the stakeholders' interview that sets the criteria for the new developments of the city. In the interviews the different stakeholders agreed that the development of the study area has the tendency to be on the vacant land creating a sprawl growth of the city, and generating a need of basic services to the new developed areas such as roads, sewages and others services, need that cannot be attended by the local government without a good planning action.

The last *"Plan Estrategico de Desarrollo Municipal" (*Strategic Plan-2009) (Goverment, 2009) for the city of Santa Cruz de la Sierra, also identifies the expansion of the city as one of the main problems caused by the development outside de boundary of the consolidate city that do not have roads or any services increasing the expenses of these basic services for all the city in order to expand the services to all the occupied land. The *"Plan de Ordenamiento Territorial"* (Strategic Territorial Plan-2005) (Goverment, 2005) identifies special areas in the city that could have new developments for the reduction of the expansion of the city.

So according to the information acquired the author identifies different criteria that will approach to the qualitative scenarios defined in section 6.4 and 6.5 of chapter 6 for this research that are shown in Table 21.

	Criteria	Description
1	Special Areas (Overlap on special areas)	Areas that area identified on the *"Plan de Ordenamiento Territorial"* (Strategic Territorial Plan-2005)(Goverment, 2005) that are considered with the capacity and characteristics to become new centres of different areas of the city.
2	Residential Areas of Low Density (Overlap on low density layer)	Areas that are based on the stakeholders interviews can have different urban densities in order to accomplish the different scenarios.
3	Residential Areas of High Density (Overlap on low density layer)	
4	Primary roads (Closer the better)	Element identified on the stakeholders' interviews as one important criterion for future developments in the different scenarios. Layer of Primary Roads – year 2009. (Local Government of Santa Cruz de la Sierra).
5	Any Pavement road (Closer the better)	Element identified on the stakeholders' interviews as one important criterion for future developments in the different scenarios. Layer of all Pavement road – year 2009 (Local Government of Santa Cruz de la Sierra).
6	Vacant Land (Overlap on vacant land)	Land identified base on the satellite image of the year 2009.

Table 21 Criteria for the suitability analysis

In the suitability analysis the higher values indicates that the land is suitable for new development, which can be in a new vacant land or increasing the density of some already build up areas, that is why in the analysis all the city in considered.

The weighting criteria for the suitability analysis are also defined by the author base on the qualitative definition of the different scenarios established by the stakeholders. Table 22 presents the values for each scenario that are implemented by the suitability wizard of the software in a scale of 1 to 10.

CRITERIA	WEIGTHING FOR SUITABILITY		
	Compact Scenario	Sprawl Scenario	Normal Trend Scenario
Special Areas (Overlap on special areas)	10	5	8
Residential Areas of Low Density (Overlap on low density layer)	0	10 (The closer the higher)	5
Residential Areas of High Density (Overlap on low density layer)	10	2.5	5
Primary roads (Closer the better)	1.5	1.5	5
Any Pavement road (Closer the better)	0	10	5
Vacant Land (Overlap on vacant land)	0	10	5

Table 22 Weighing table for the suitability analysis

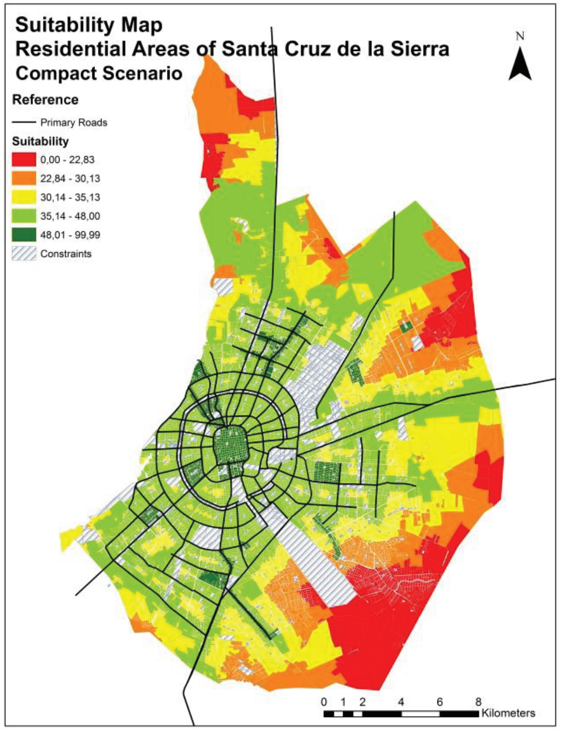


Figure 23 Suitability Map for Compact Scenario

For the compact scenario the higher values are concentrated in the special areas, CBD and the area with tendency for more developments identified in the analysis of the actual conditions of the City. Also they are located closer to the primary roads.

Lower values are located in vacant land avoiding the expansion of the city and keeping vacant land as rural and natural like the vision of the compact scenario shapes.(Figure 23)

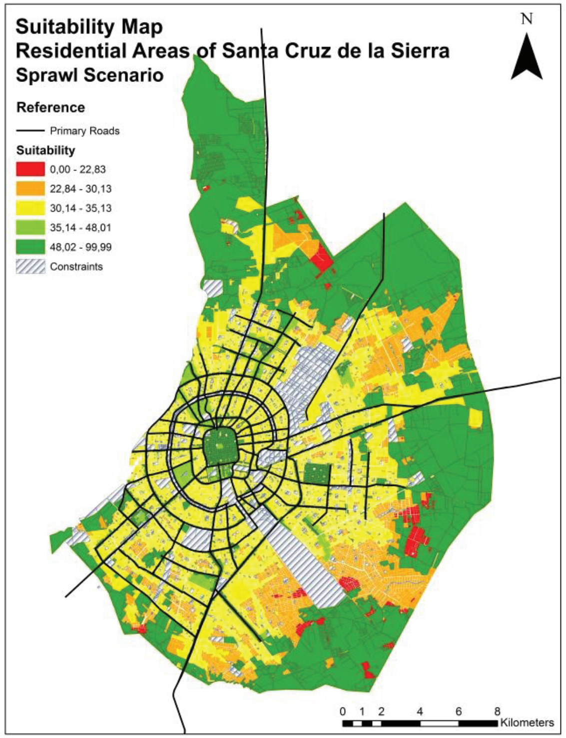


Figure 24 Suitability Map for Sprawl Scenario

Sprawl Scenario identifies the vacant land with the higher values allowing the city expansion, but also has some high values in the special areas and the areas with tendency for more developments identified in the analysis of the city.

Middle values are in the already build up area of the city while lower values do not appear much allowing the expansion of the city. (Figure 24)

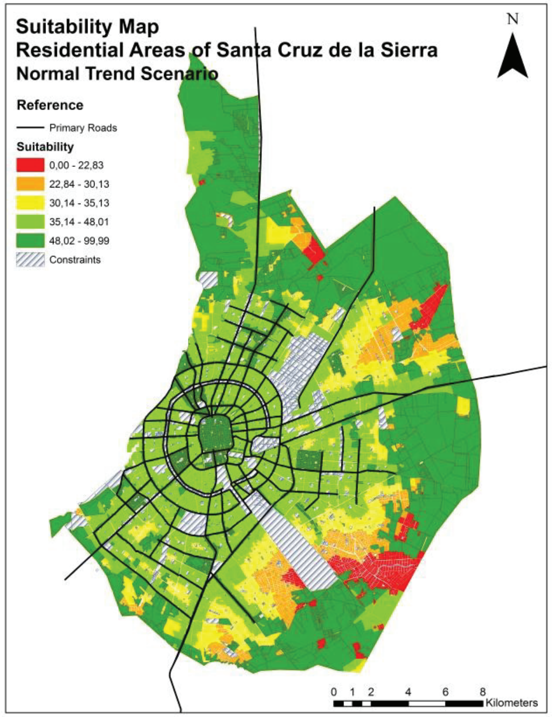


Figure 25 Suitability Map for Normal Trend Scenario

Higher values are concentrated in the special areas and the area with tendency to more developments identified in the analysis of the city. Also higher values are in the whole build up area of the city.

Lower values are located in some vacant lands that are away from the primary road. This scenario tries to show the normal trend of the city development. (Figure 25)

7.2. Land Allocation .-

The land allocation step was done by allocating the requirement of the land demand based on the projection of the population and the housing demand for each year in the most suitable areas identified in the previous step and the maximum urban density capacity of each block (polygon) already calculated for the entire city in the base layer of the model presented in Figure 22. (Section 6.8).

The base layer for the allocation analysis has a field created according to the urban norms that will give the maximum build up capacity of each block of the city. Table 23 shows the elements considered in the base layer for the allocation analysis.

Element (field)	**Definition**
Shape Area	Mts2.
Land Use	Residential.
Zone	Identification of each polygon (feature) with an urban zone code.
IA (Index of Occupancy)	Mts2 according to each zone.
Height allowed	Mts according to each zone.
Maximum Urban Density	Calculation of the maximum capacity of each plot.
Suitability	**Score obtained in the previous step (suitability analysis)**

Table 23 Elements of the base layer to calculate the allocation land

The allocation method used is the standard or strict order allocation that "uses a simple algorithm that places the next building or unit in the most desirable remaining location"(Tutorial, 2009). According to this method the most suitable blocks will be allocated first until its capacity is full and then follow to the next until the demand is completed, leaving the least suitable for the last. This method is selected because allocates the demand (mts2 of residential units) in areas that are considered most suitable according to the suitability analysis done in the previous step for the creation of the scenarios based on the different criteria that each one has. In addition it helps to visualize the maximum capacity of each block defined by the urban norm.

The land allocation was done for each scenario through the 14 years of period selected for the stud, Figure 26 presents the land allocation of the compact scenario for the years 2015 and 2020, where it can be seen that the majority of the land allocated is in the already build-up areas as a densification process and only few vacant land is urbanized.

In Figure 27 the allocation for the sprawl scenario for the years 2015 and 2020 are shown and as the policy for this scenario was the outgrowing, it can be seen that in the year 2015 all the vacant land is urbanized and even outside of the urban area boundary, by the year 2020 the allocation of the new land start to increase a little the density of the already build-up city, especially in the blocks located closer to the primary roads.

The normal scenario in Figure 28 also takes mostly all the vacant land and starts to increase the densification on the areas that were detected in the section of the study area (Chapter 5).

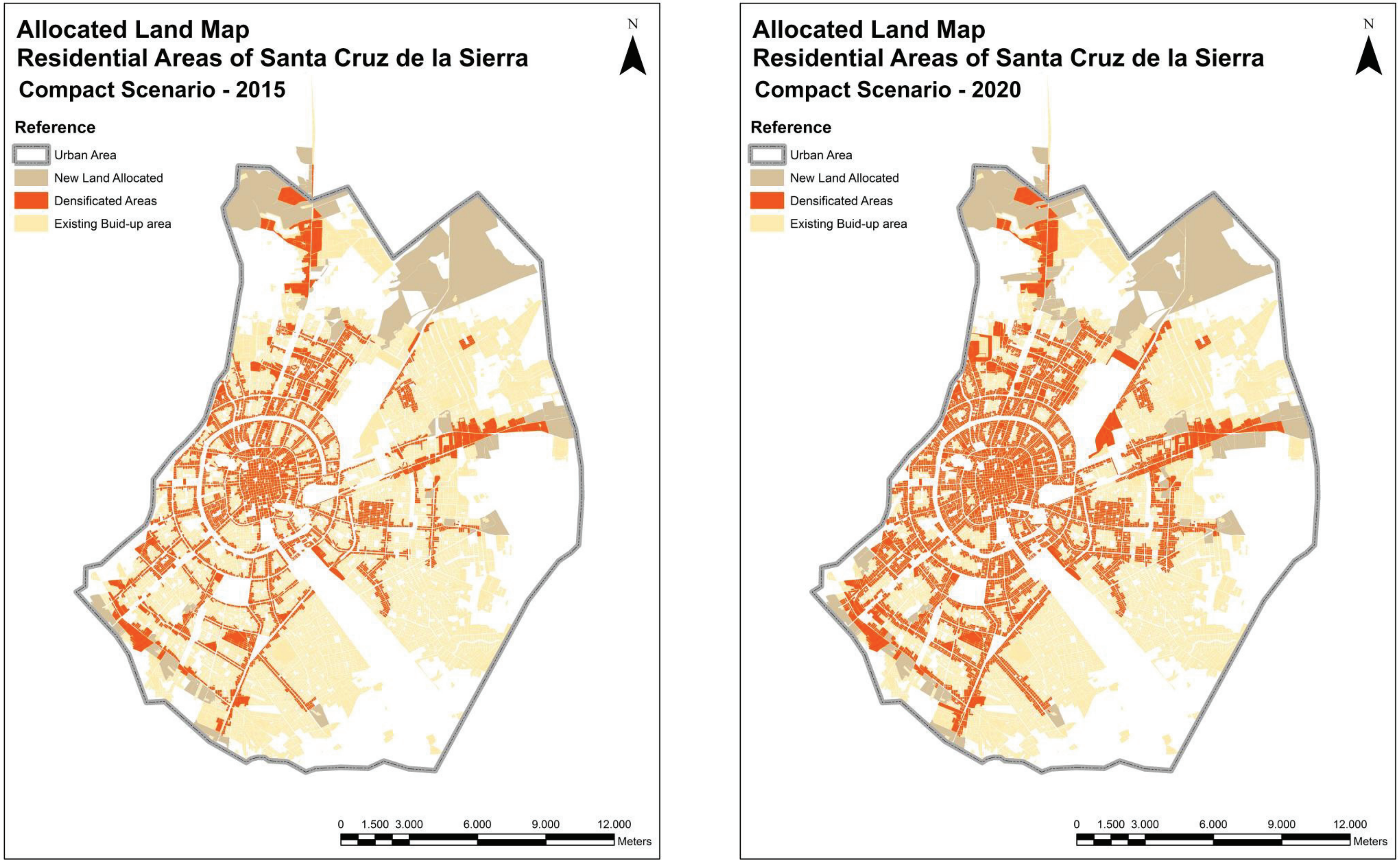


Figure 26 Allocated Land Map Compact Scenario 2015-2020

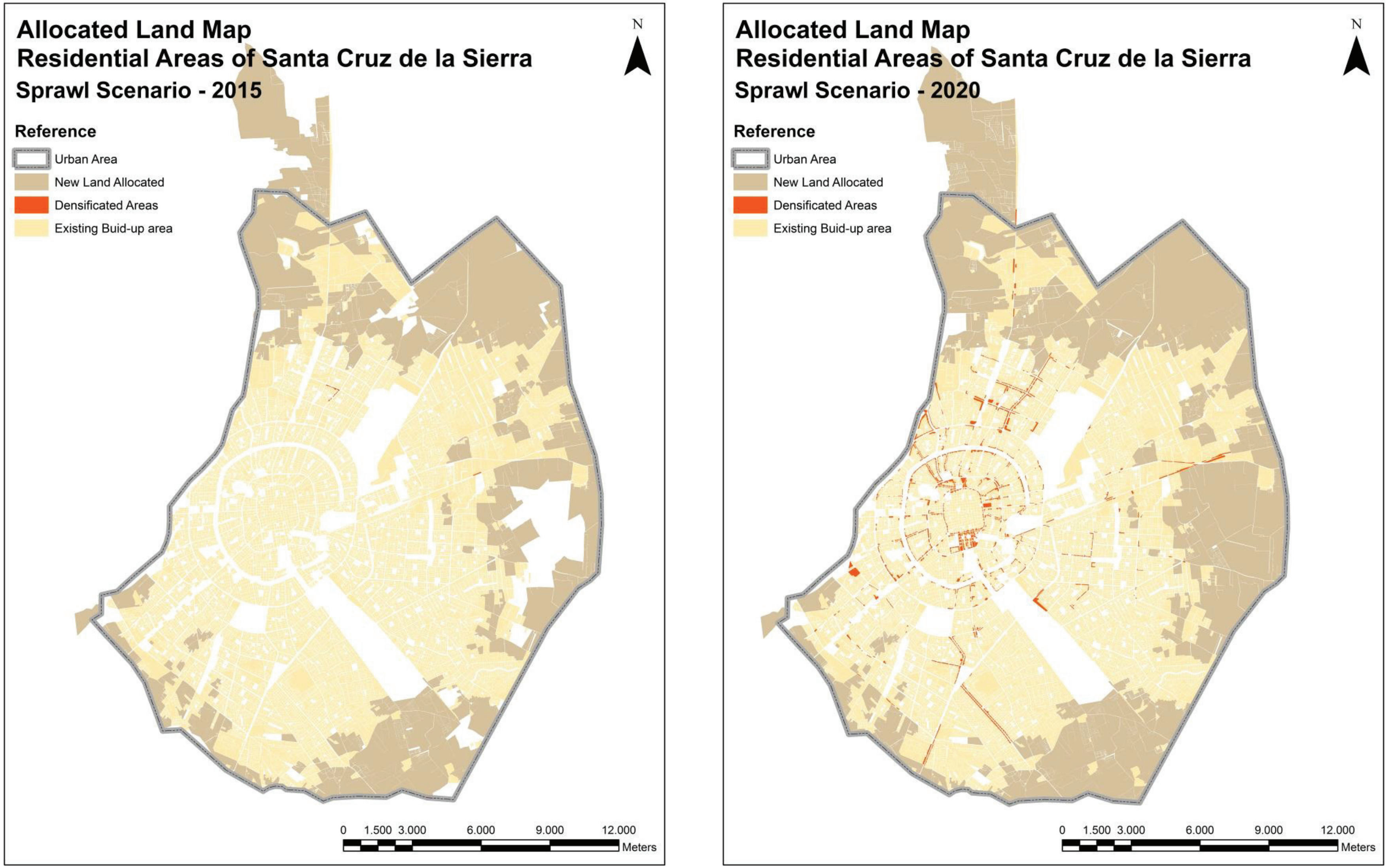
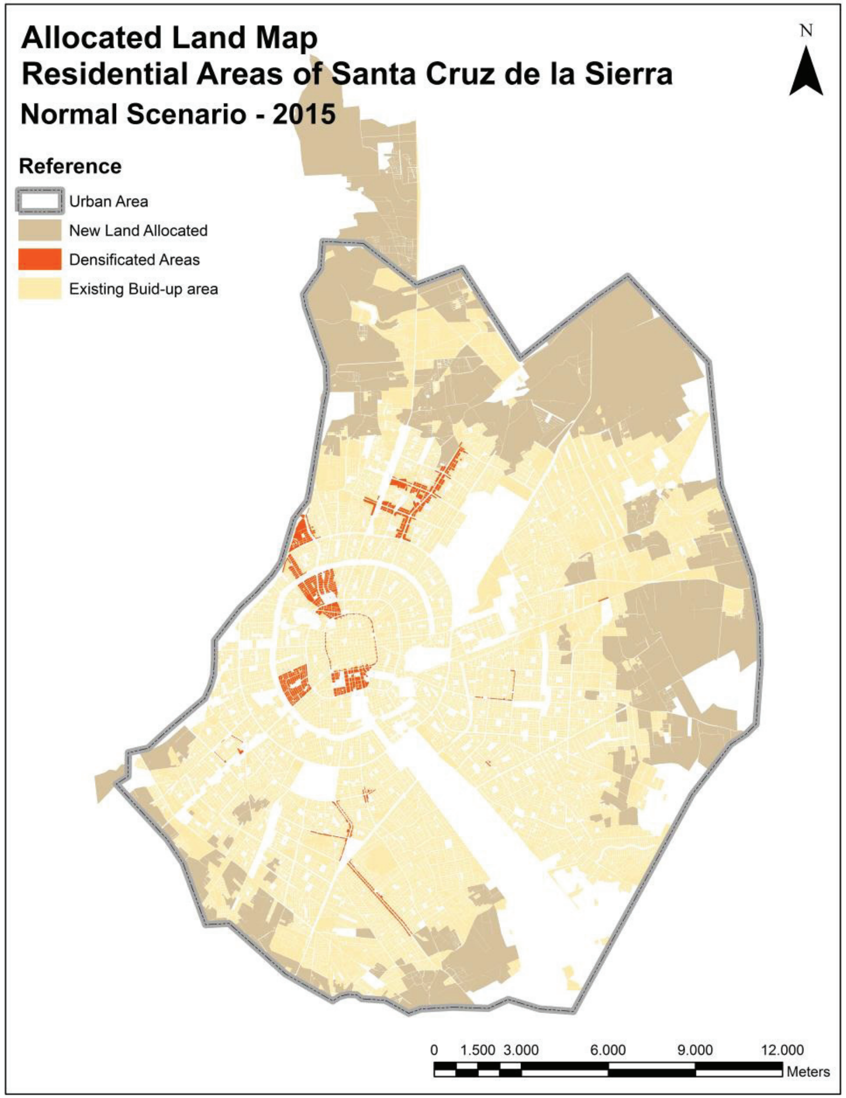


Figure 27 Allocated Land Map Sprawl Scenario 2015-2020



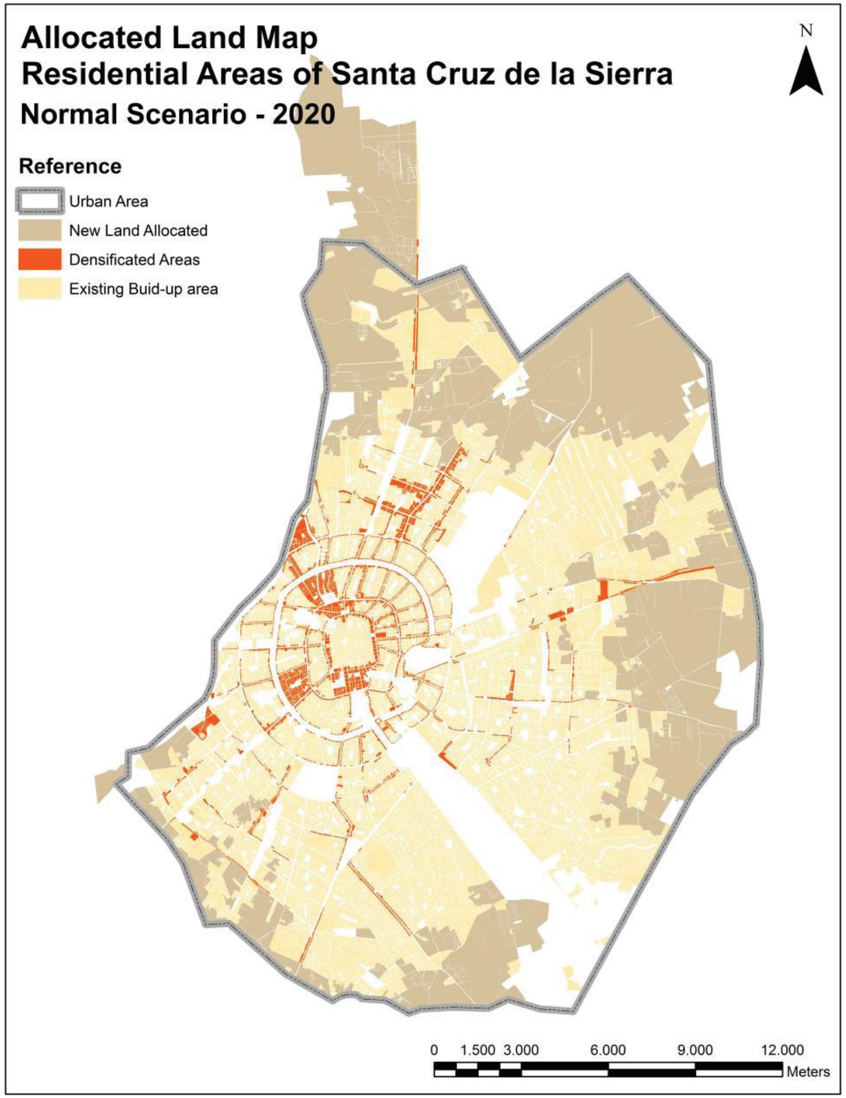


Figure 28 Allocated Land Map Normal Scenario 2015- 2020

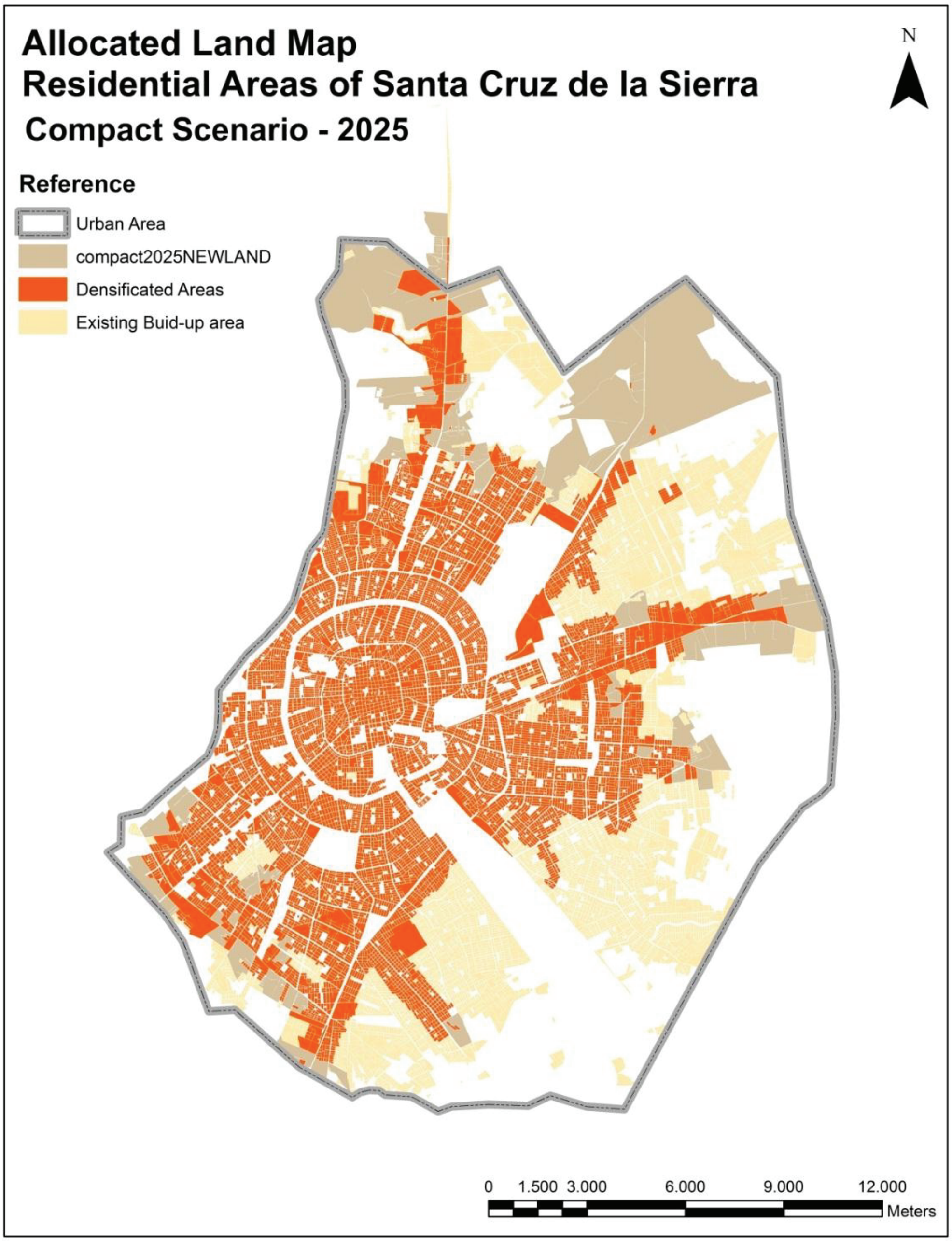


Figure 29 Allocated Land Map Compact Scenario 2025

The compact scenario in the year 2025 of Figure 29, allocates first the land in the areas that are close to the primary road and increase the urban density in the CBD and areas that are identified with tendency to increase their development avoiding the vacant land. This result follows the vision of a compact scenario that ensures new developments increasing the density and closer to already build-up areas and roads, keeping the rural or natural land empty.

Sprawl Scenario locates all the vacant land of the urban area without considering any new developments in the already built-up area. The expansion of the city continues even when some areas are not well connected to the road system. Figure 30.

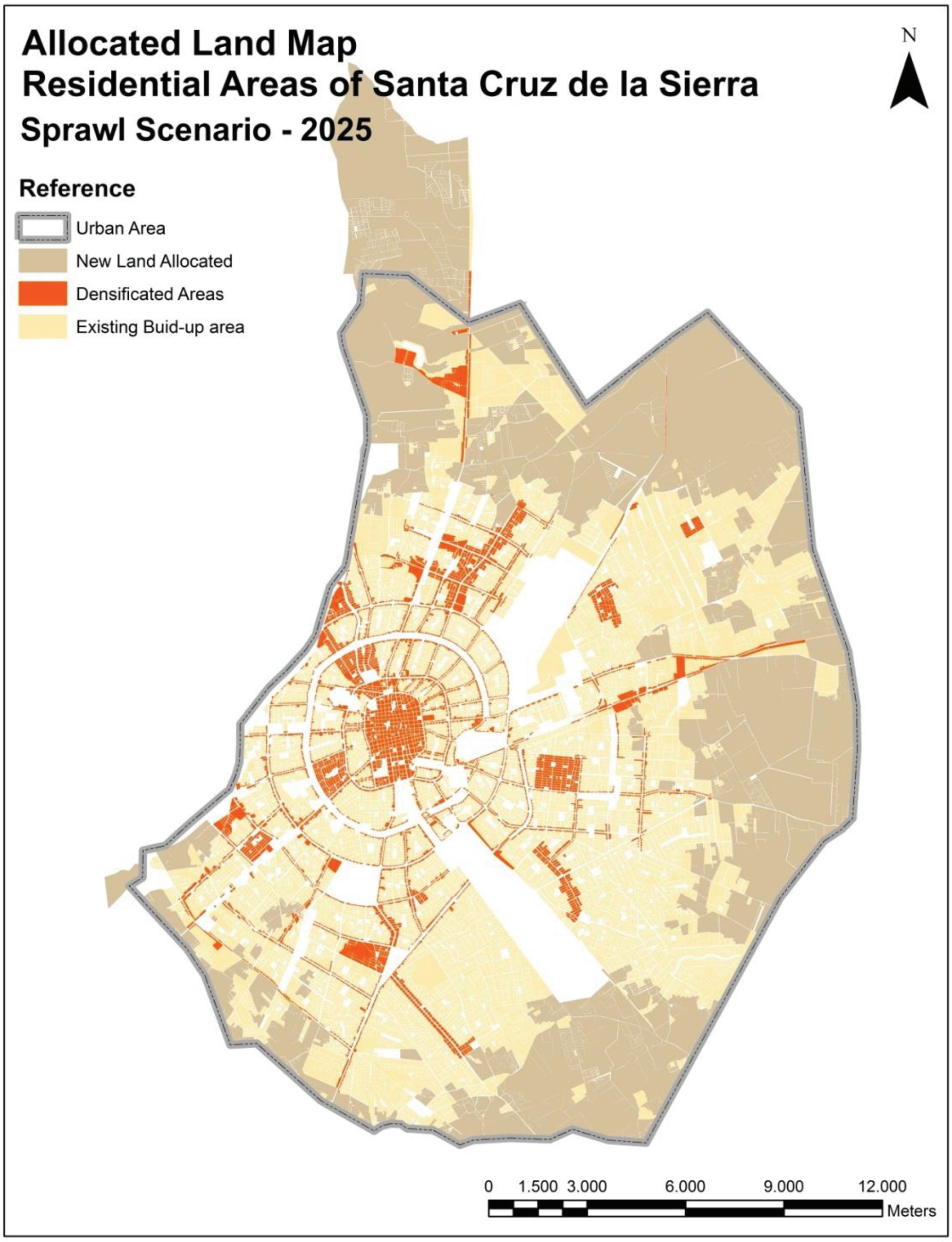


Figure 30 Allocated Land Map Sprawl Scenario 2025

The Normal Trend scenario in Figure 31 tries to express how the city will develop in the normal condition, vacant land is allocated with new developments as well as the areas that are now developing with higher densities. But the trend still goes to the vacant land first.

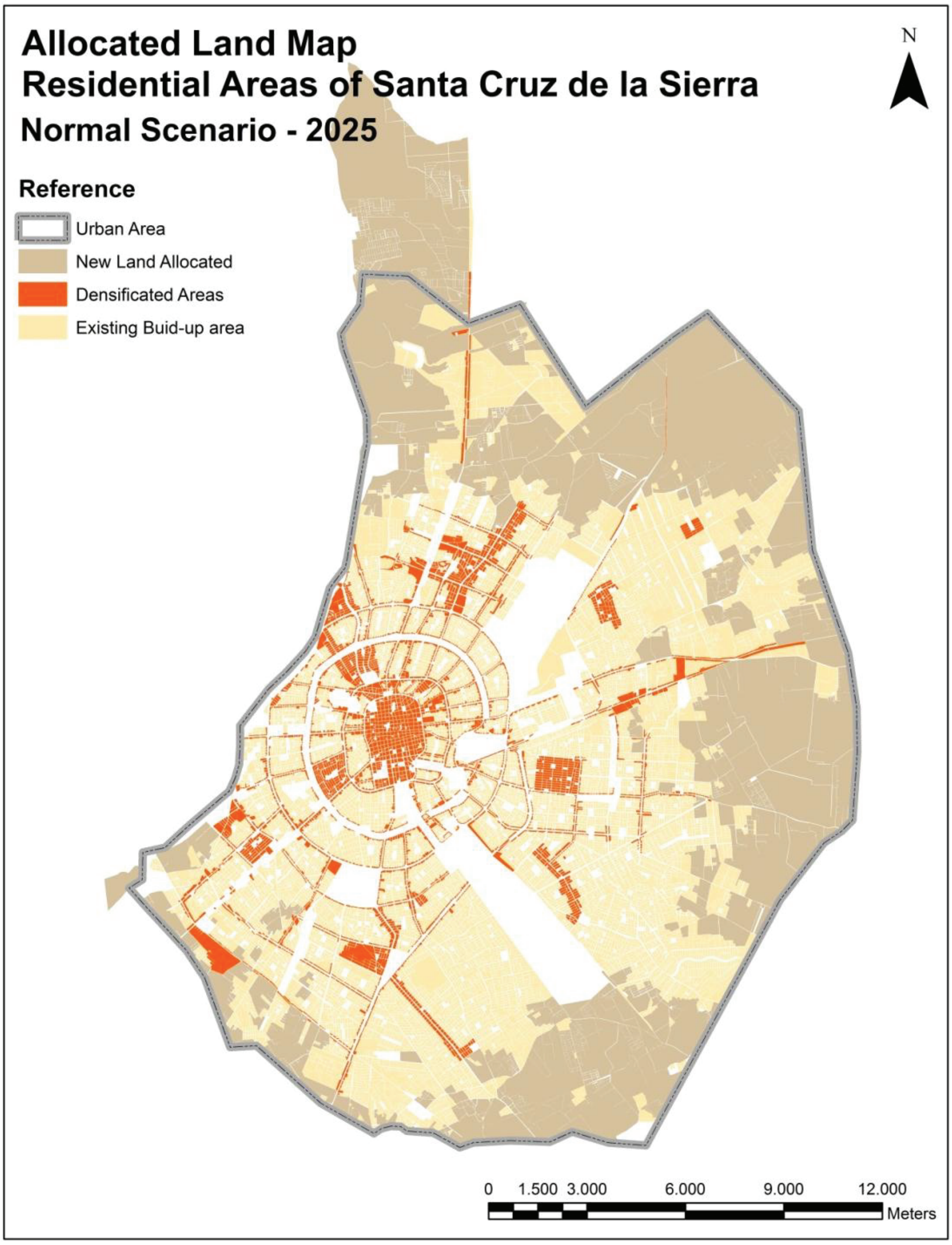


Figure 31 Allocated Land Map Normal Scenario 2025

7.3. Land Allocation with a different Urban Density .-

The land allocation with a different urban density step was done by allocating the requirement of the land demand based on the projection of the population and the housing demand for 2025 in the most suitable areas identified in the previous step. The maximum urban density of each polygon has been increased following the same process that was explained in Figure 22. (Section 6.8).

The allocation method used for this step is the same explained in section 7.3.

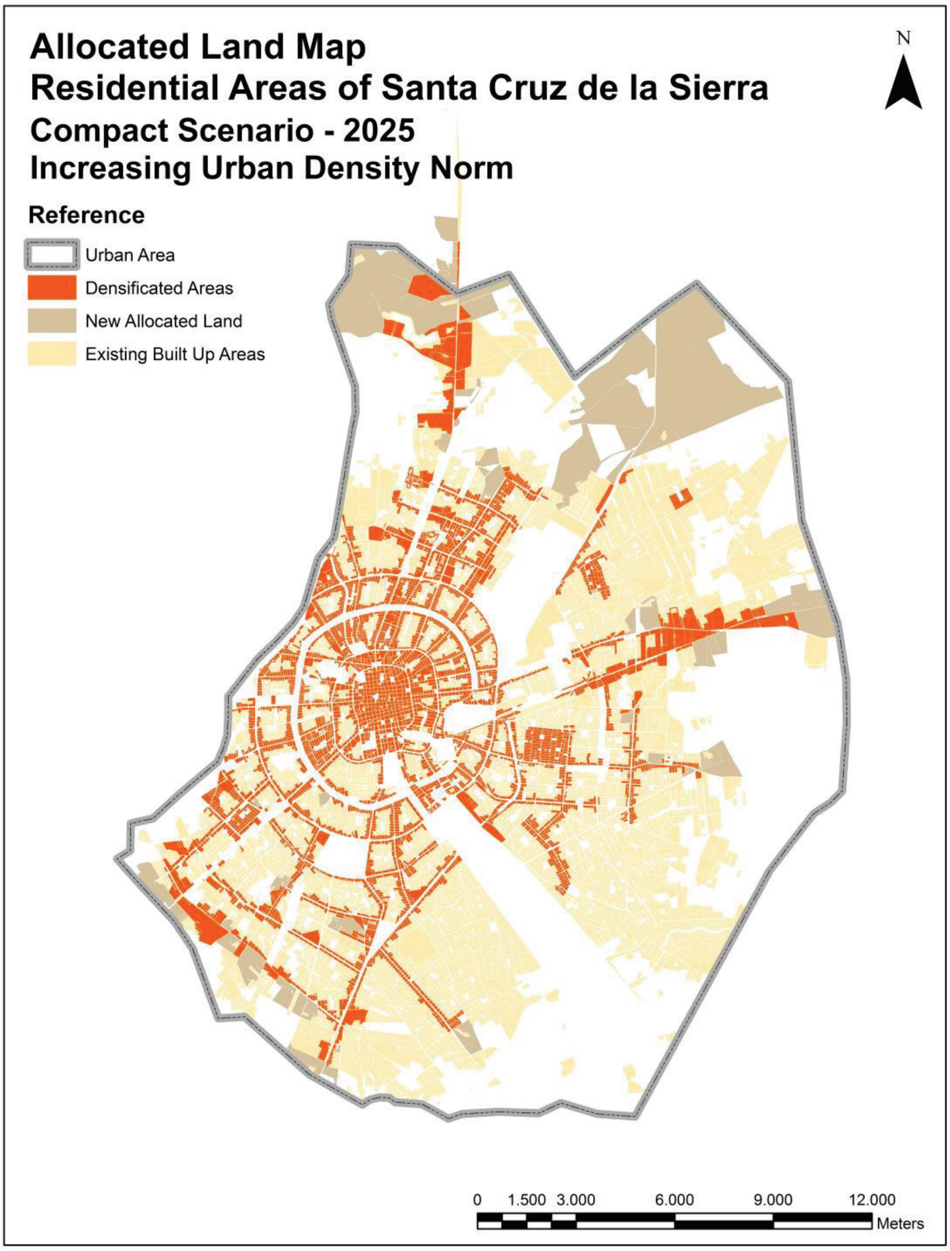


Figure 32 Allocated Land Map Compact Scenario 2025 with variation on urban density norm

The compact scenario in the year 2025 with variation on urban density norm of Figure 32, allocates first the land in the areas that are close to the primary road and where the density has increased like the CBD and the areas that were identified with tendency to raise their development avoiding most of the vacant land. This result follows the vision of a compact scenario that ensures new developments increasing the density and closer to already build-up areas and roads, keeping the rural or natural land almost empty.

Sprawl Scenario 2025 with variation on urban density allocates all the vacant land of the urban area first without increasing the built-up area. This is due to the increased of the urban density norm in each part of the city. The expansion of the city continues even outside of the urban area established. Figure 33.

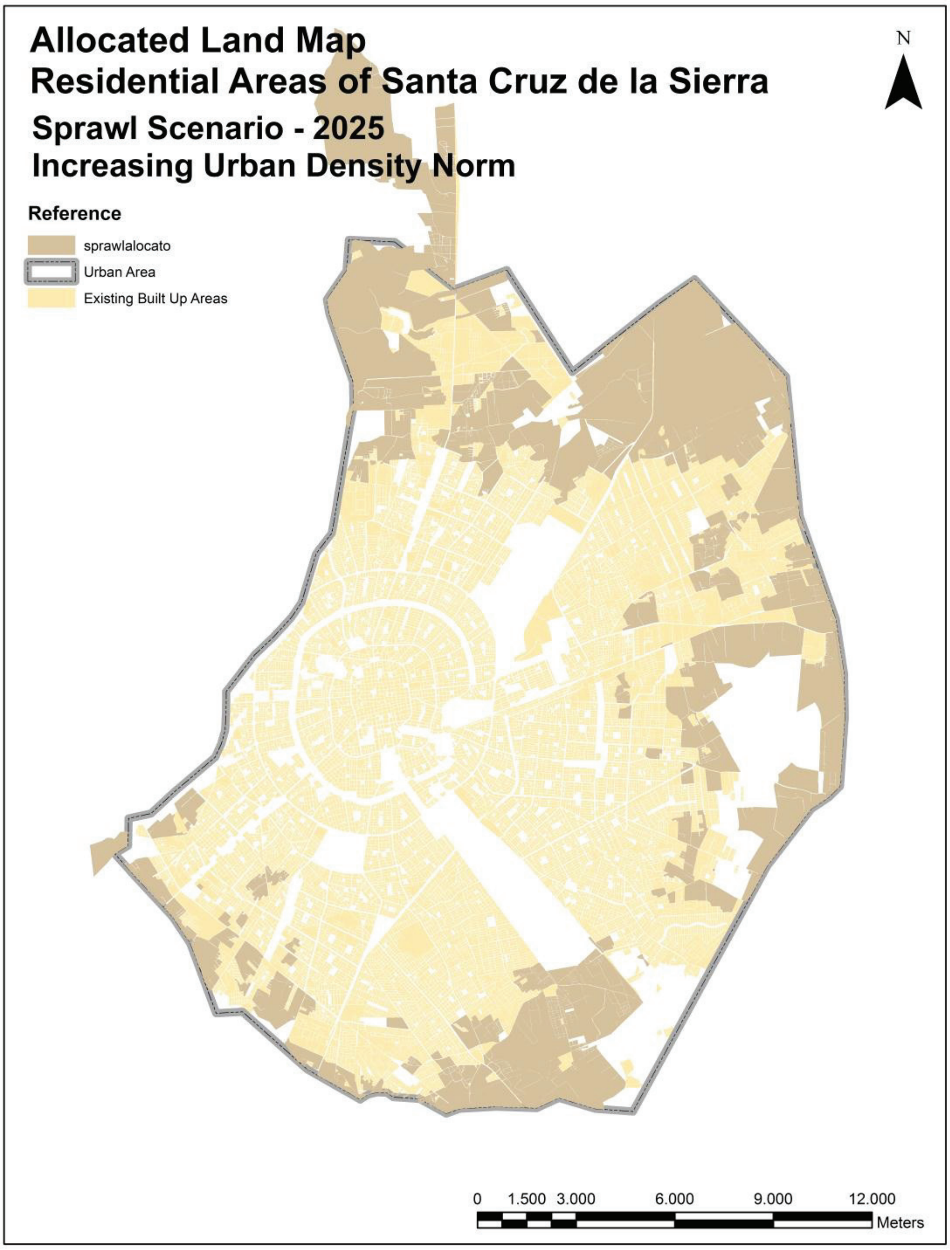


Figure 33 Allocated Land Map Sprawl Scenario 2025 with variation on urban density norm

The Normal Trend scenario 2025 with the variation on urban density norm in Figure 34 tries to express how the city will develop in the normal condition with the difference that the norm has increased. So the urban vacant land is allocated with new developments as well as the areas that are now developing with higher densities. But the trend still goes to the vacant land first.

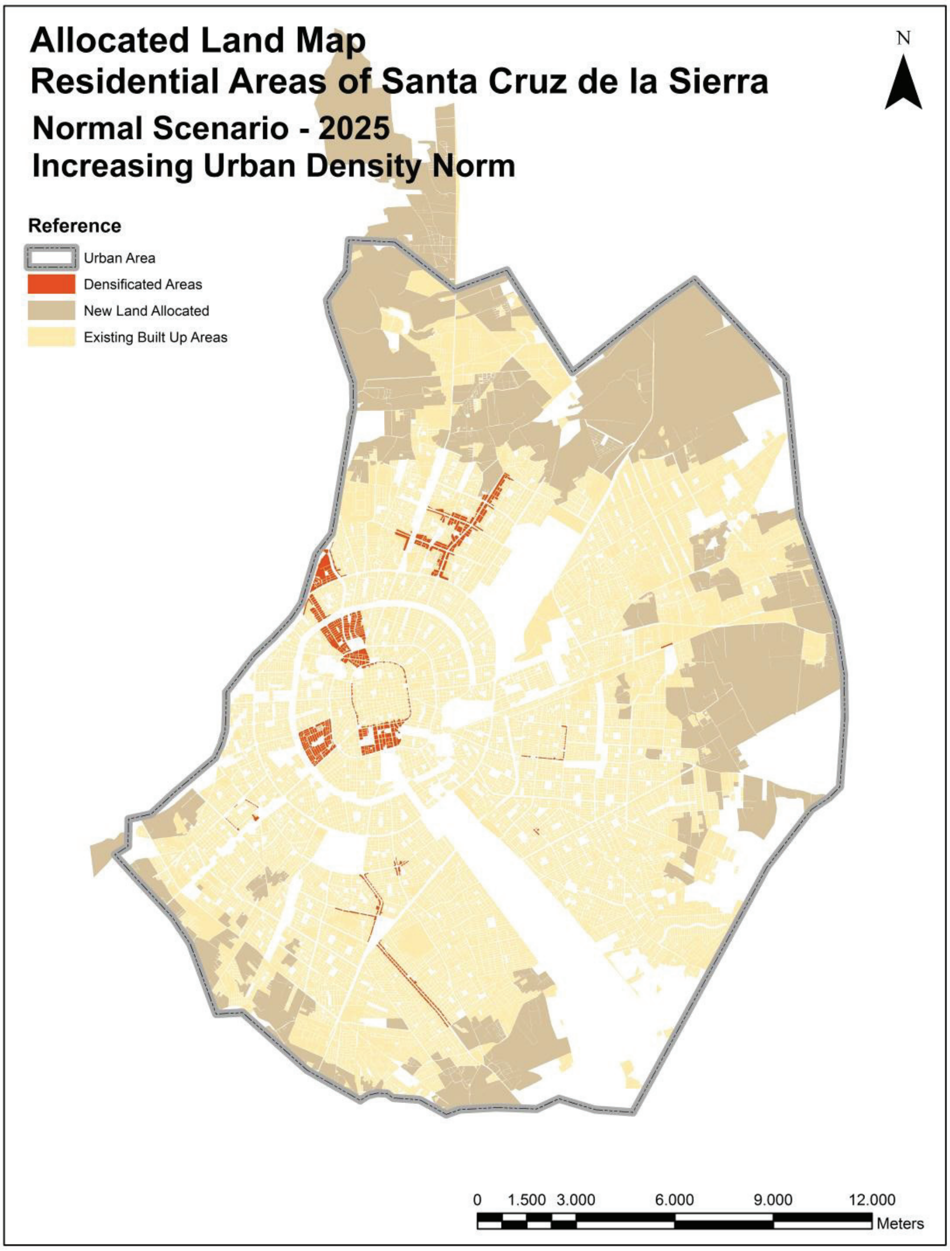


Figure 34 Allocated Land Map Normal Scenario 2025 with variation on urban density norm

7.4. 3D model of the built- up of the scenarios. (Urban density).-

The urban density refers to the built-up area analysis that calculates the maximum capacity of each block in the city towards to see how the urban norms impacts in the development of the city, its urban context and sustainability. The base layer for the urban density analysis uses the same field that the allocation analysis did, the maximum of the urban density for each block which expresses the urban norms of the city. Table 24 shows the elements considered in the base layer for the urban density analysis.

Element (field)	Definition
Shape Area	Mts2.
Land Use	Residential.
Zone	Identification of each polygon (feature) with an urban zone code.
IA (Index of Occupancy)	Mts2 according to each zone.
Height allowed	**Mts according to each zone.**
Maximum Urban Density	**Calculation of the maximum capacity of each plot.**
Allocated Land	**Score obtained in the previous step (allocation analysis)**

Table 24 Elements of the base layer for the urban density analysis

The urban density model is calculated to obtain the maximum capacity of mts2 that a block can have and it gives a possible image of how the city can turn if the norm is completely applied and if the new developments follow the criteria settled for each scenario. How the process of the calculation for this step is explained in section 6.8.

The Compact scenario in Figure 35 for the year 2025 shows an increase of all the heights of the blocks in the already build up area of the city allowing with this to keep vacant land as the vision defined. The CBD increases to its maximum capacity and most of the city achieves a height of 9 to 12 meters. Buildings of less than 9 height meters are in the new developments outside the build-up areas.

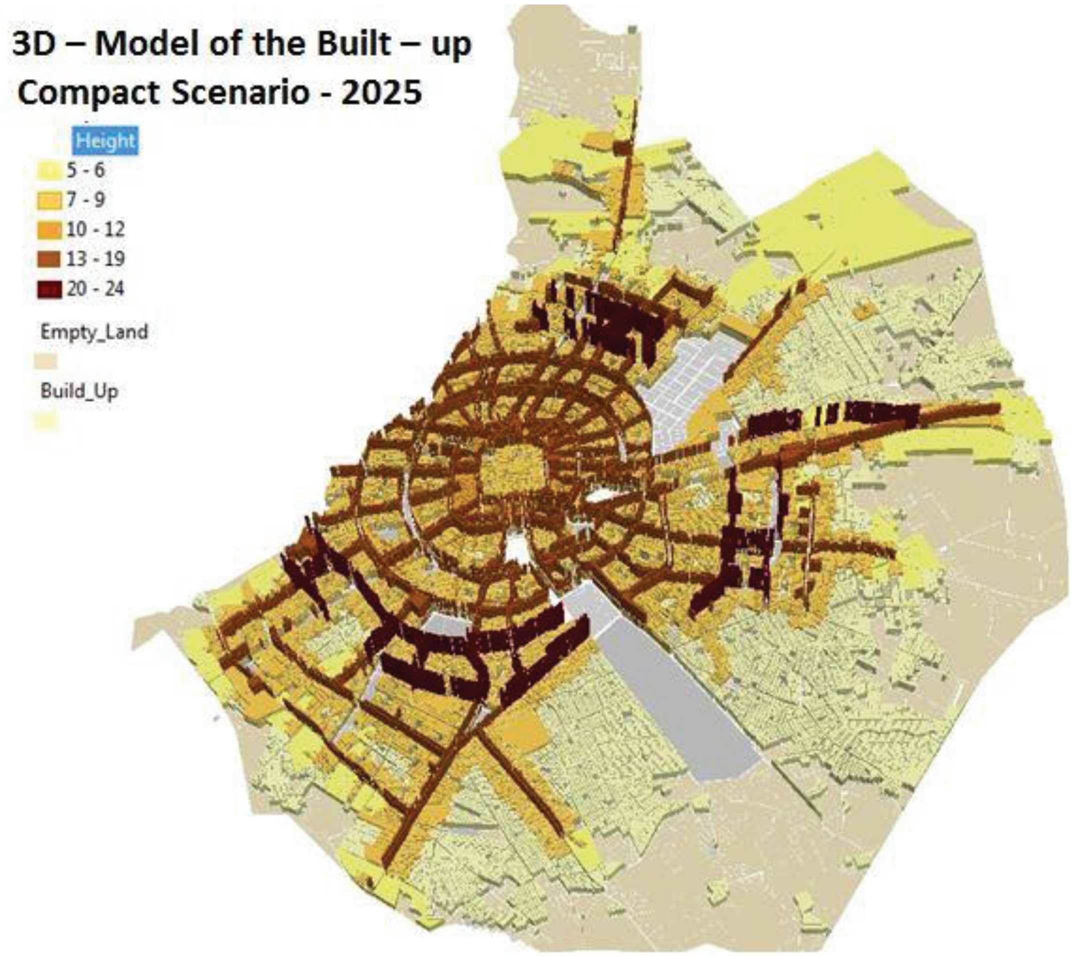


Figure 35 3D Model of the Compact scenario 2025

In Figure 36 the same Compact scenario 2025 but with the urban norm increased presents that no new land have been urbanized, the capacity of the already built-up area have been increased and it is able to attend all the demand. It can be seen that blocks located in the primary roads as the vision defined are with higher buildings taking advantage of the urban norm of that sector.

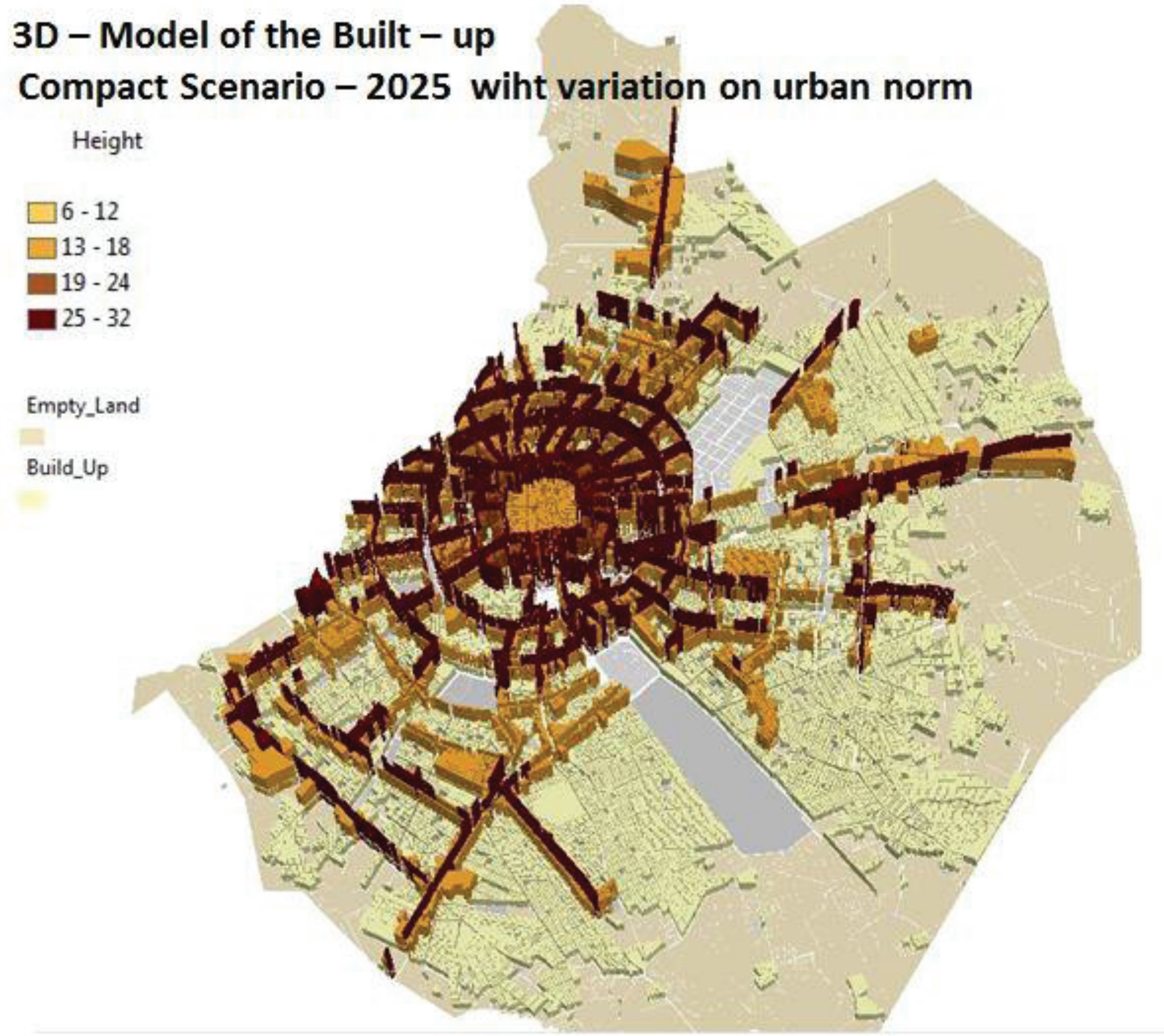


Figure 36 3D Model of the Compact scenario 2025 with variation on urban norm

The Sprawl scenario in Figure 33 of the year 2025 follows the vision of the scenario occupying all the vacant land available even outside of the urban radio established by the *"Plan de Ordenamiento Territorial"* (Strategic Territorial Plan) 2005(Goverment, 2005) The higher heights of the buildings are located in the primary roads moving towards to the inside of the neighbourhood with a very low height buildings.

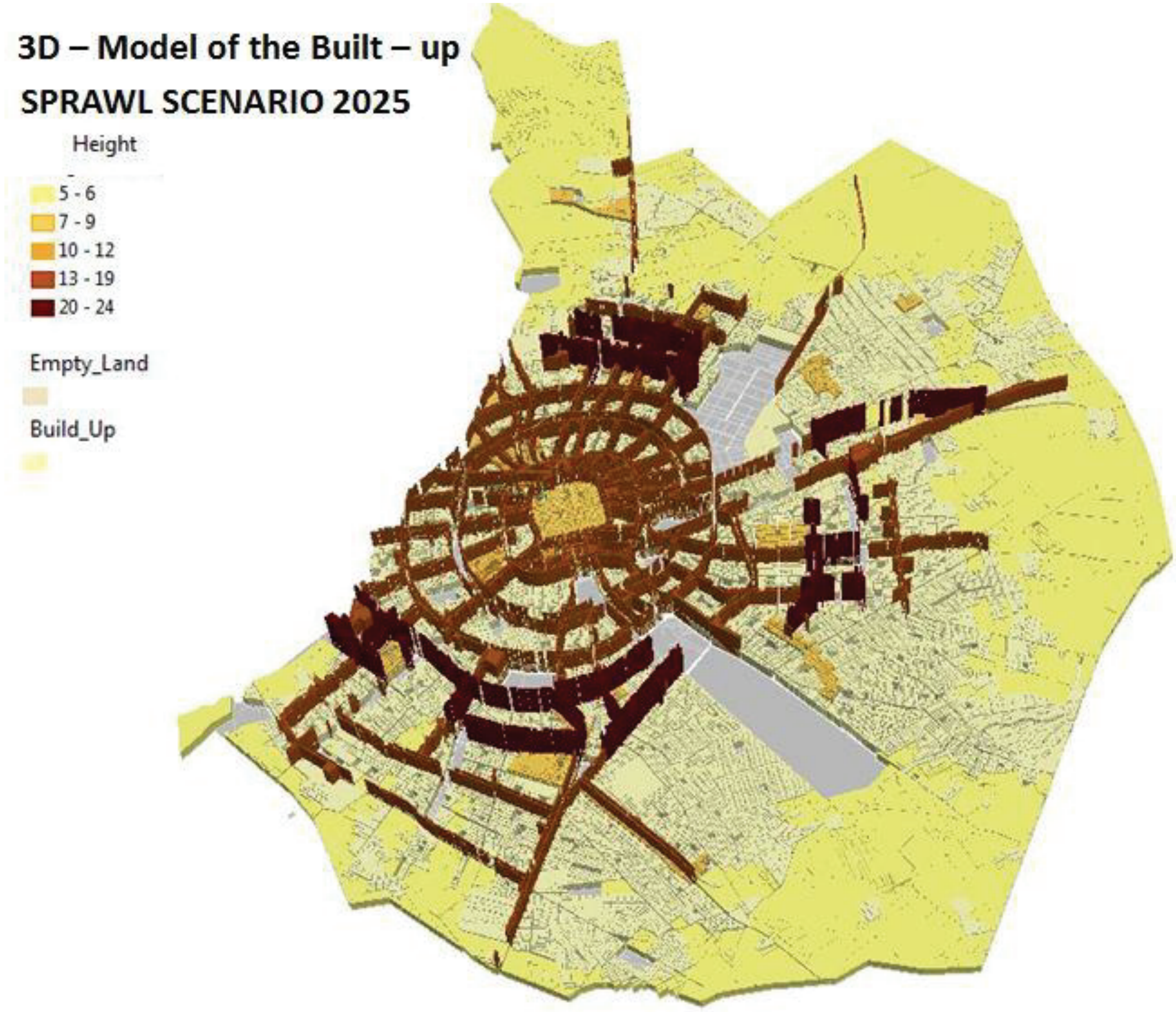


Figure 37 3D Model of the Sprawl scenario 2025

Figure 38 of the Sprawl of the year 2025 follows the vision of the scenario occupying all the vacant land available even outside of the urban radio established by the *"Plan de Ordenamiento Territorial"* (Strategic Territorial Plan) 2005(Goverment, 2005) . For this scenario there is not any densification as the urban capacity of the new land it is enough for the allocation of the demand for the year 2025.

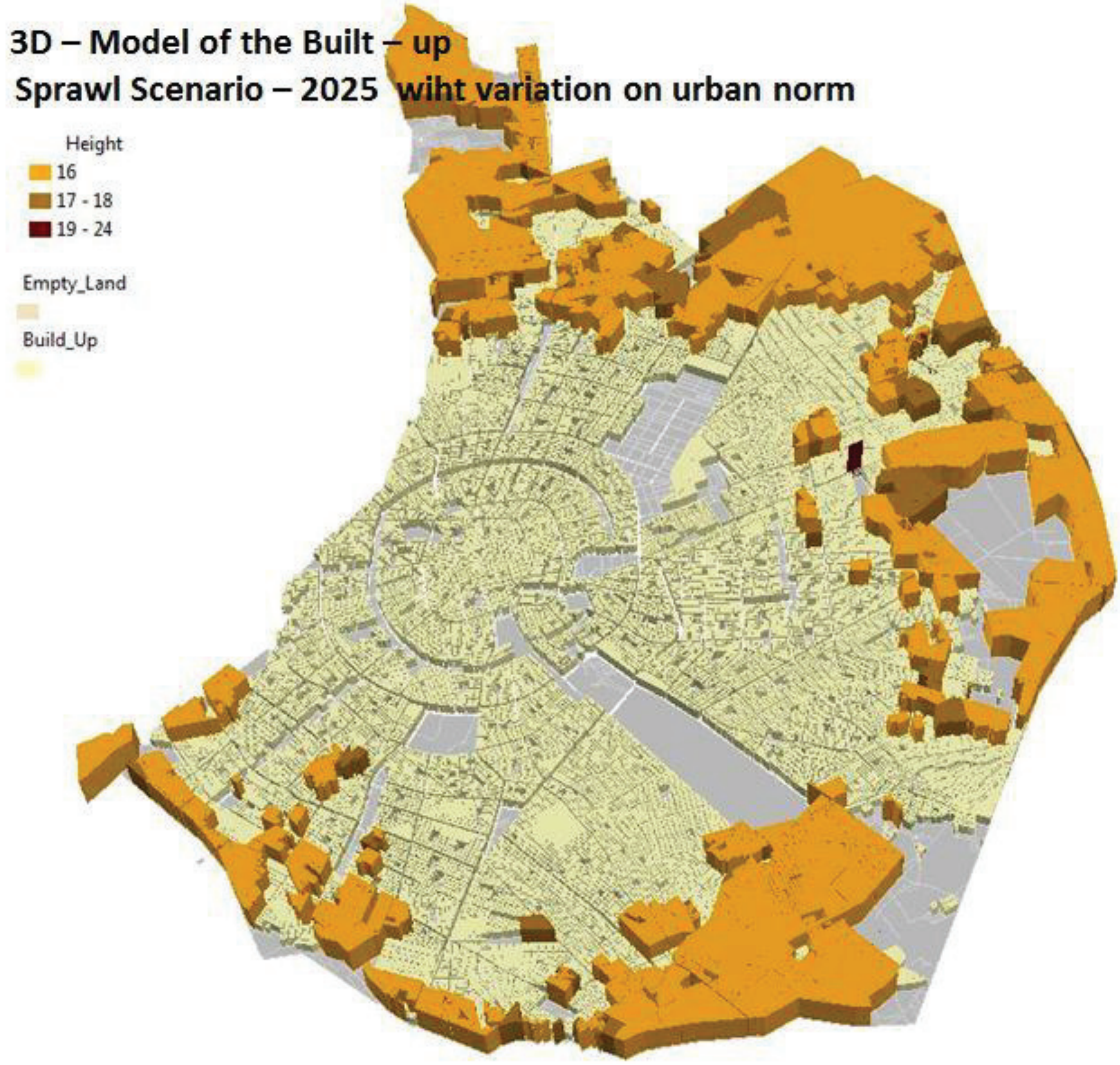


Figure 38 3D Model of the Sprawl scenario 2025 with variation on urban norm

The Normal Trend scenario in Figure 39 of the year 2025 is a possible future of the city based on how its actual development is, the continuous expansion of the city occupied all the vacant land and also some areas that are outside of the urban radio established by the *"Plan de Ordenamiento Territorial"* (Strategic Territorial Plan) 2005(Goverment, 2005) The higher heights of the buildings are located in the primary roads moving towards the inside of the neighbourhood with a very low height building but in the areas that the author identified in the analysis of the actual situation higher densities are located as well as in the special areas settled by the *"Plan de Ordenamiento Territorial"* (Strategic Territorial Plan) 2005 (Goverment, 2005).

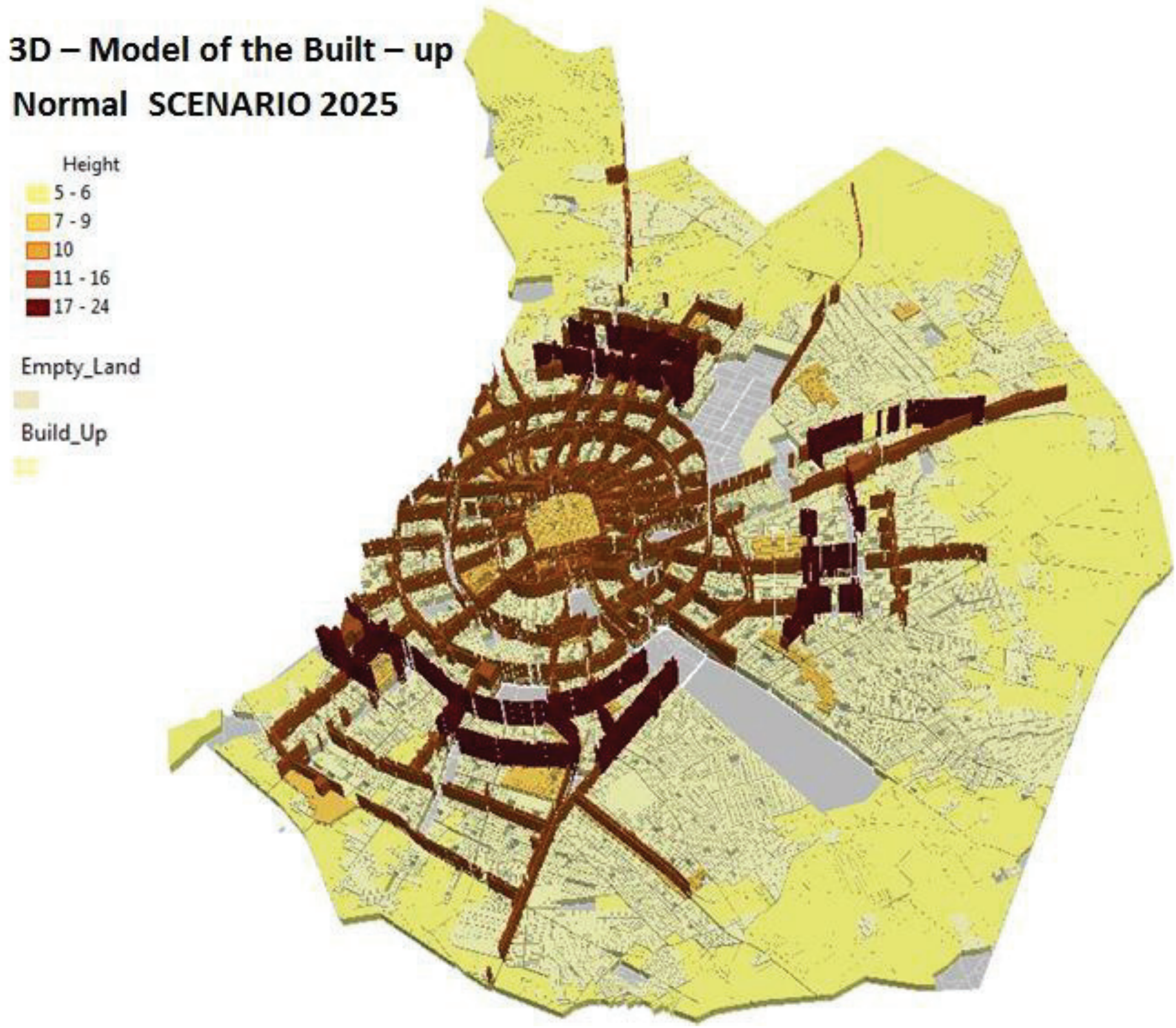


Figure 39 3D Model of the Normal scenario 2025

Figure 40 of the the Normal Trend scenario with variation on urban norm of the year 2025 shows how the areas with actual development will still increasing its density according to the new urban norm. The vacant land is partly urbanized fulfilling the demand of new developments.

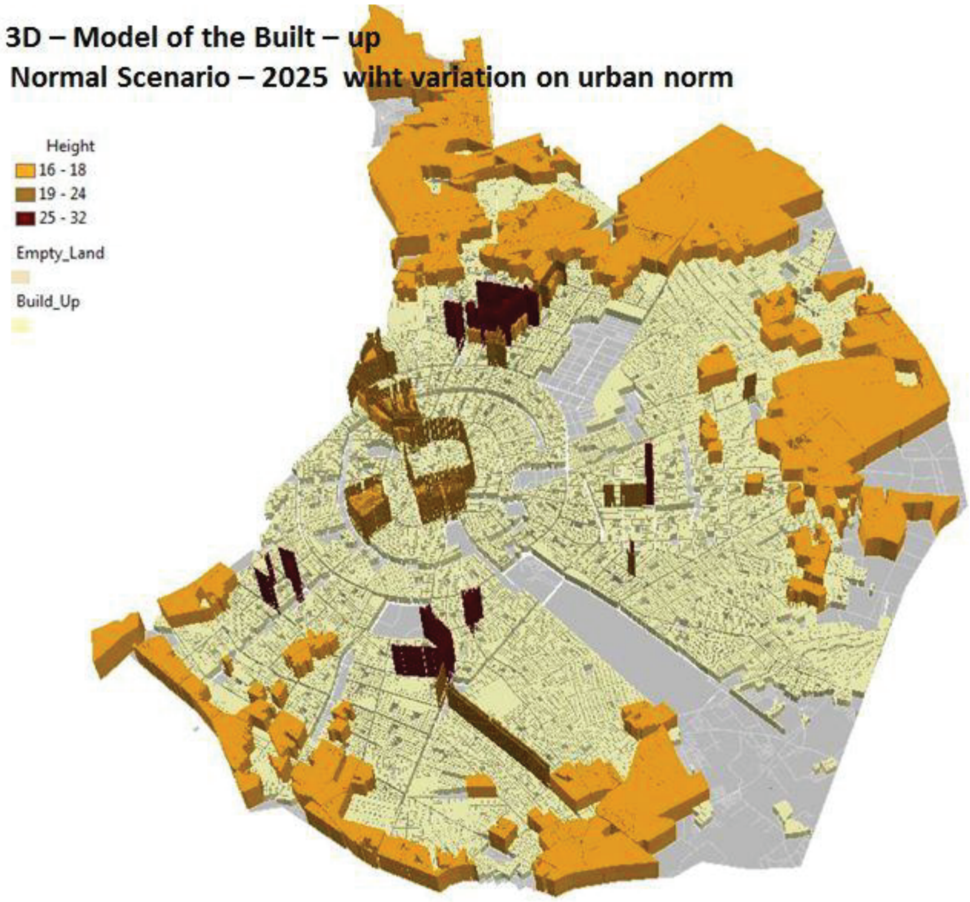


Figure 40 3D Model of the Normal scenario 2025 with variation on urban norm

8. SCENARIO EVALUATION

This chapter discusses how the different plausible scenarios modelled can be evaluated based on different indicators that are identified during the fieldwork.

8.1. Definition of indicators for the scenario evaluation.

The definition of the indicators for the scenario evaluation is the result of the work group discussion, where the stakeholders selected different indicators according to the actual problems of the city that would help to achieve a sustainable development in the future years.

Based in the conclusion that the city of Santa Cruz de la Sierra has had five Urban Masters Plans in its last 50 years in which all of them followed the same directions, every time allowing the use of more vacant land for the new developments leading to a fragmented city with lacks of basic services, bad public transport services or bad accessibility to basic services. And on the result of the work group discussion four indicators are selected that will help to assess the scenarios and to understand how the actual urban norm will have an impact on the future urban growth of the city in order to achieve a sustainable development.

- ✓ Space Consumption
- ✓ Green Areas
- ✓ Accessibility to basic services
- ✓ Road Congestion

In addition in section 6.3 , the main problems addressed in this study were identified that were based on The *PDM-Plan de Desarrollo Municipal 2009-2015* (Municipal Urban Plan2009-2015)(Sierra, 2009):

1. Physical Space Dimension. - This refers to construction delays of the basic infrastructure and equipment due to the fast expansion of the city.
2. Territorial Dimension. - The model of the city has been broken and now shows a fragmented city very dispersed with very low densities and without respecting any natural areas.

8.1.1. Indicator: SPACE CONSUMPTION

8.1.1.1. Definition of the indicator

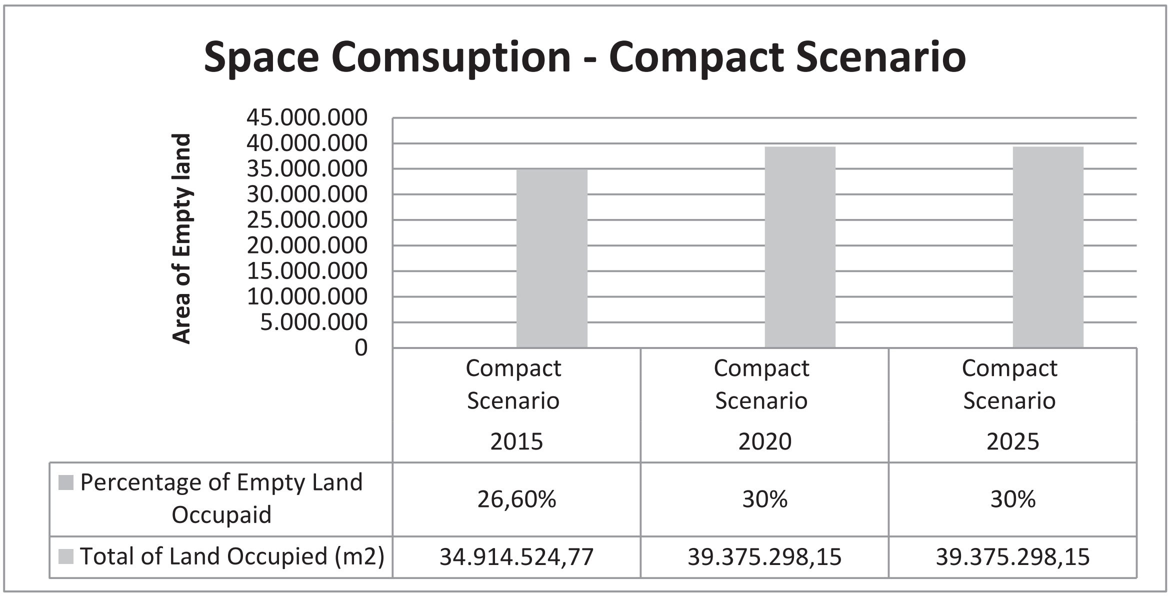
Amount of vacant land available in relation of urban area projected for the city.

8.1.1.2. Justification

Space consumption refers to the critical problem that the world is facing with the consumption of the land, its growing number shows the uncontrollable expansion of the city losing all the natural areas that could have and should be preserved. This measure not only express the amount of land lost it also shows the fast growing of the city.

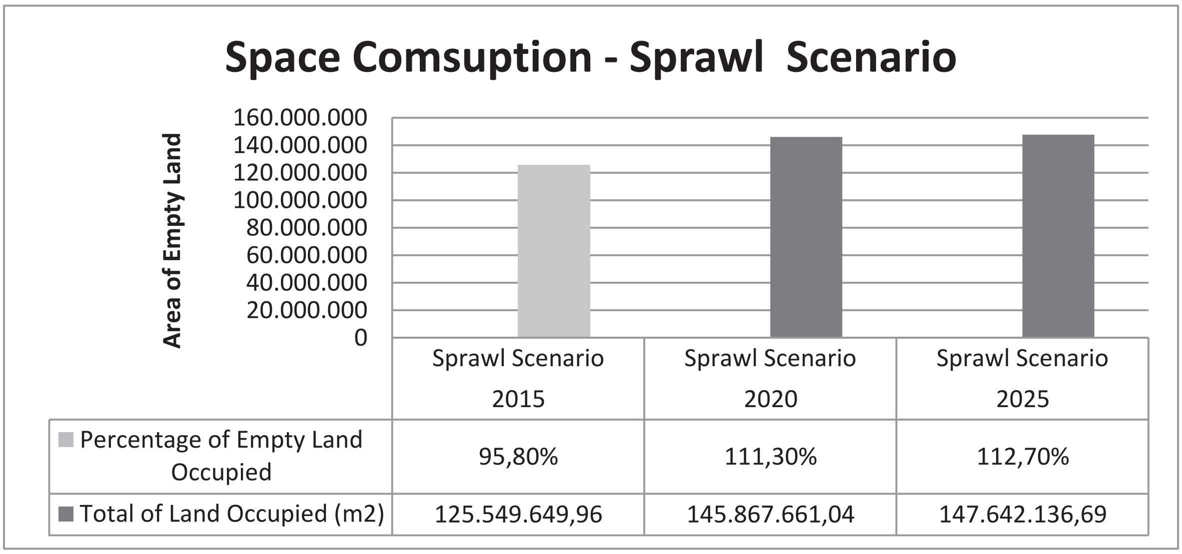
8.1.1.3. Operationalization

The indicator was calculated from the total land vacant of the city according to the urban area established by the *"Plan de Ordenamiento Territorial"* (Strategic Territorial Plan) 2005(Goverment, 2005) and the total land allocated in the vacant land areas of each scenario.



	Compact Scenario 2015	Compact Scenario 2020	Compact Scenario 2025
Percentage of Empty Land Occupaid	26,60%	30%	30%
Total of Land Occupied (m2)	34.914.524,77	39.375.298,15	39.375.298,15

Table 25 Space Consumption of the Compact Scenario



	Sprawl Scenario 2015	Sprawl Scenario 2020	Sprawl Scenario 2025
Percentage of Empty Land Occupied	95,80%	111,30%	112,70%
Total of Land Occupied (m2)	125.549.649,96	145.867.661,04	147.642.136,69

Table 26 Space Consumption of the Sprawl Scenario

The results of Tables 25, Table 26 and Table 27 helps to discuss that from the vacant that the study area has in the year 2009 policies for compact scenarios have less space consumption as it still has vacant land available to be developed in the year 2025. On the other hand the sprawl scenario already occupies all the land by the year 2020 generating more space consumption over its capacity according to the vacant land available. The normal scenario has a little less impact on the land consumption but at the end in the year 2025 it runs out of land occupying a 111% of the land, growing outside of its approved urban area.

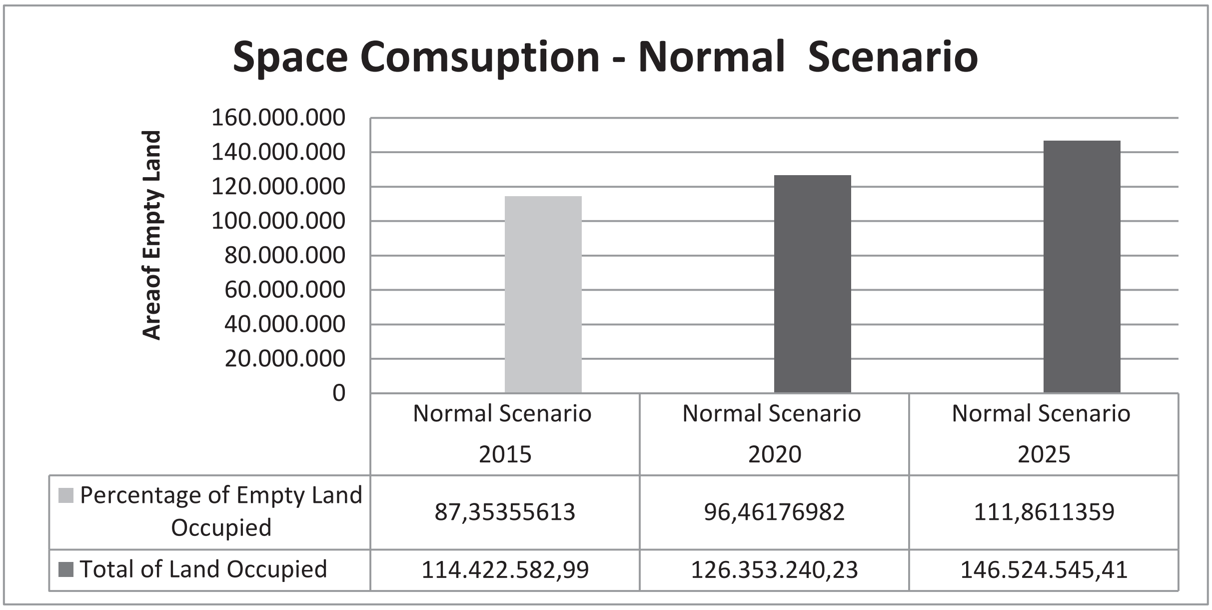


Table 27 Space Consumption of the Normal Scenario

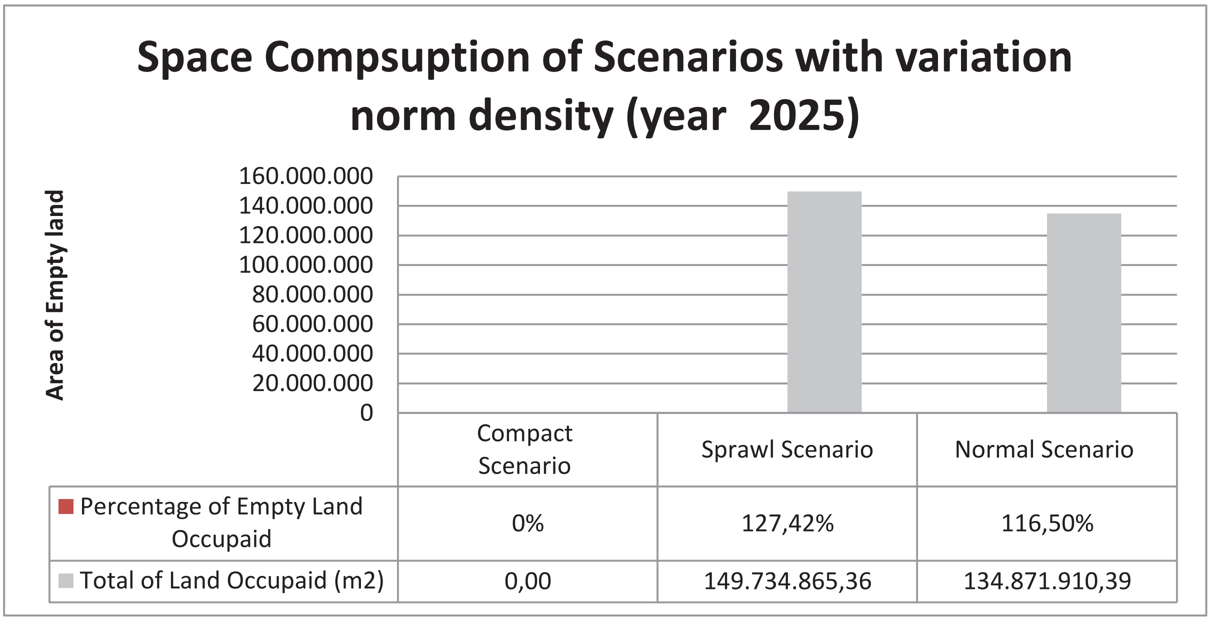


Table 28 Space Consumption of Scenarios in year 2025 with variation norm density

Table 28 present the impact of the variation in the urban density , where the Compact scenario has 0% in land consumption for the year 2025 and the other two scenarios Sprawl and Normal have more that the land available in the urban area.

8.1.2. Indicator: GREEN AREAS

This indicator refers to the amount of green areas in relation to the population. (mts2 per person)

8.1.2.1. Definition of the indicator

The Green area indicator refers to the urban green areas that the city has in tits build-up area in relation of the population of the city.

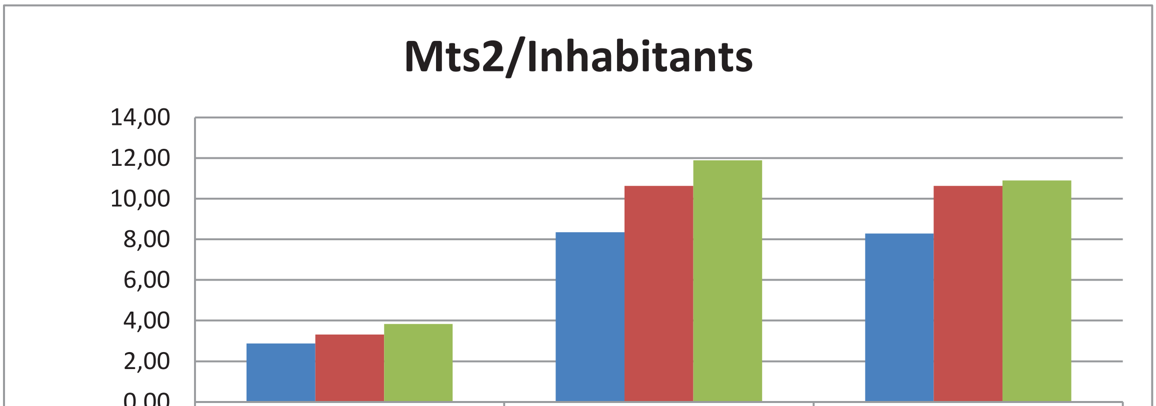
8.1.2.2. Justification

This indicator helps to see the amount of green areas that area between the build-up areas which are important elements on the context of a sustainable city because of their impact on the environment.

8.1.2.3. Operationalization

The indicator was calculated based on the land use map from the base line year of 2009 where the green areas are identified. For the allocated land of each scenario a calculation is made based on the basic cell unit of design of the city (the neighbourhood) and an amount of the discounted for public use is designated to the green areas of that block.

The limitation of the calculation is that in the vacant land the spatial location of the green area could not be identified and only an area is calculated of each block as the distribution of the green areas varies according to the design of the designer.



	Compact Scenario	Sprawl Scenario	Normal Scenario
Year 2025	2,87	8,34	8,28
Year 2020	3,31	10,63	10,63
Year 2015	3,83	11,89	10,90

Table 29 Indicator of Green Areas mts2/inhabitants

In Table 30, the analysis is based on year 2025 with different scenarios and different policy option in the norm related to the urban area, the results presents that compact scenario has the same average than the previous one as there was no new developments, for the Sprawl and Normal scenario is a decrease in the average but this is because there is less land urbanized than in the scenarios with the actual norm.

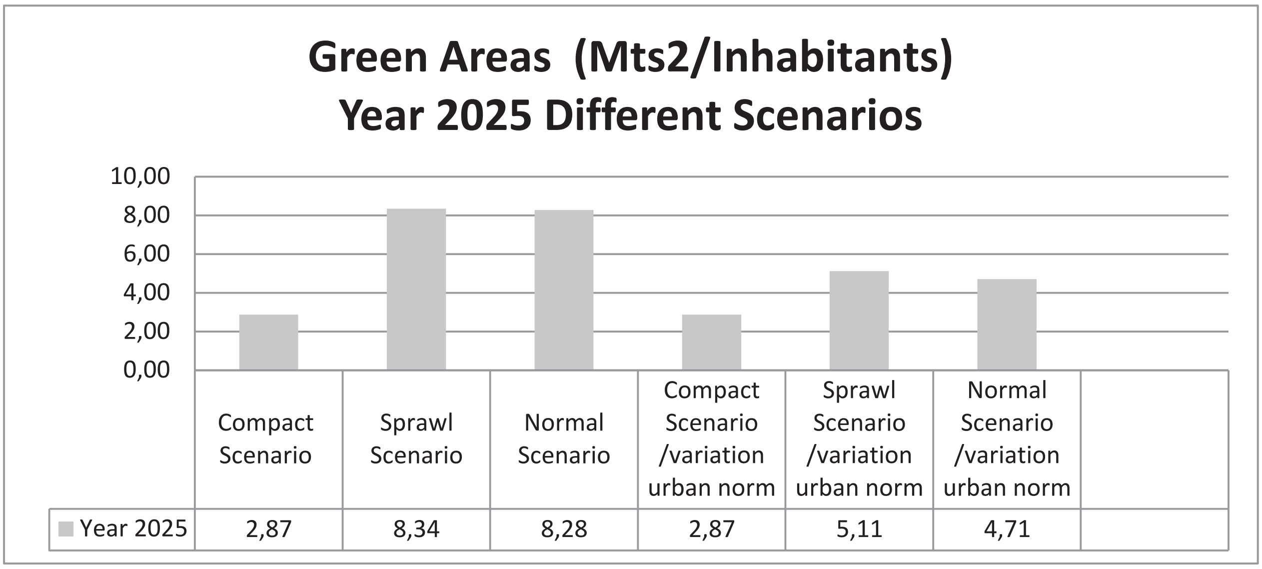


Table 30 Indicator of Green Areas mts2/inhabitants in Year 2025 with different Urban Norm

This indicator helps to visualize the amount of green areas by inhabitant, and the results in Table 29 shows that the average of the compact scenario is the lowest in relation of the sprawl and normal scenario. Nevertheless this indicator is based on the actual policies of the city where no special areas have been implemented for green urban areas and just assuming that the city will keep growing with the same pattern. With this information decision- making can define different policies for the improvement of the average.

8.1.3. Indicator: ACCESIBILITY TO BASIC SERVICES

This indicator refers to the people's accessibility to basic services

8.1.3.1. Definition of the indicator

This indicator refers to the service coverage area of the health facilities based on their maximum capacity of the Health Facility.

8.1.3.2. Justification

This indicator helps to see how the different trends in the development of the city can make a difference on the accessibility of the people to basic services.

8.1.3.3. Operationalization

The indicator is calculated according to the existing data of the actual hospital that the city has and the analysis of the accessibility to them thru the road network. A network analysis is done based in the conventional distance of 15 Km for the coverage area then the amount of people living in that area is calculated.

The limitation of this indicator is that there is no data on projects for new hospitals so the future population will be attend by the same amount of units that the base line year has. Also the lack of information of the road network for the future vacant land does not allows getting a good output. Further development on this indicator is needed as well as data collection.

8.1.4. Indicator: ROAD CONGESTION

This indicator refers to the amount of car that the primary roads can hold.

8.1.4.1. Definition of the indicator

This indicator refers to the amount of cars that the primary roads can hold.

8.1.4.2. Justification

The indicator helps to see how congested will be the road in the different trend of scenario development of the study.

8.1.4.3. Operationalization

This indicator is calculated based on the design of the road which has a maximum capacity and the amount of people living in those areas. For this indicator the information of people move around the city, the specific job areas and the pick hours of the traffic must be needed.

8.1.5. Limitations

The indicator were selected from the fieldwork according to the stakeholders and the problems identified in The *PDM-Plan de Desarrollo Municipal 2009-2015* (Municipal Urban Plan2009-2015)(Goverment, 2009) in order to respond to the actual problems of the city, the lack of information for the farther development of the last two indicators did not allow to get the results.

9. RESULTS

This chapter presents the main contribution of the research and revisit the findings of the proposed objectives of the study.

The main objective of this research was to develop scenarios to support planning decision to achieve a sustainable urban development for the city of Santa Cruz de la Sierra – Bolivia. The idea was to evaluate different scenarios according to the built-up urban norm of the city that refers to the density of the plots. The scenarios were developed based on the future visions of a group of stakeholders; that were developed on a 3D Model. In conclusion an evaluation was made with indicators that the stakeholders identified according to the actual problems of the city.

9.1.1. To identify the different attributes of urban density that will help to address urban sustainable development.

Urban density is an important measure that helps to address the analysis of many issues related to the urban environment and its population according to the different definitions that are presented in table 1 from the chapter 2. All this different attributes can help to achieve urban sustainability as a part of a whole analysis not in an independent variable because it has correlations with a vary variables of the city design.

9.1.2. To identify a set of sustainable urban indicators to measure the urban sustainability of the city.

More than to identify the most sustainable indicator to measure the urban development of the city, the research identified four indicators that at the present time are representative to the city because are main problems of its development.

The task of identifying suitable indicators for the development of the study area involve many areas that due to the lack of data and the time constrain could not be assessed. Two indicators out of the four selected were quantifying.

9.1.3. To identify the aim for the city of Santa Cruz de la Sierra, for its future sustainable urban development.

From the results of the data collection activity it can be seen that there are many opinion of how the city must be and many converging ideas as well as many differences between the stakeholders. The only point in which all agreed was the control of the expansion of the city.

9.1.4. To developed different scenarios for the sustainable urban development of the city of Santa Cruz de la Sierra.

The development of a model that allows visualizing and analysing how the city may unfold in the next 14 years is the main finding of this research. The model permits to understand how the urban density through its normative can affect the sustainable development of the city as well to see how the urban context may be visualized in the different scenarios.

9.1.5. To measure the impacts of urban density in the city of Santa Cruz de la Sierra.

The model developed helps to see how the urban density will impact on the city in many ways, first calculating the urban density of population over meters square, second analysing the urban architectural context of the final outputs of the scenarios calculation the build-up and non-build-up area and finally assessing the impact of the urban density with two of the indicators selected.

9.1.6. To assess the sustainable urban development of the city of according to the new strategies implemented.

After the prior findings, it can be concluded that this is not possible to assess with only four indicators and the application of two different policies options that were urban control growth and urban density. On the contrary it was found that density is one part of the many variables that must be studied in order to have a better understanding on its way towards sustainability.

10. CONCLUSIONS

This chapter discuss the main conclusions as well as the recommendations for the improvement of the model for further research.

10.1. Conclusion

The literature review conclusion explain that the interpretation of sustainable urban development has a broad and context definition, and the debate remains open for farther research for the most adequate path towards the sustainable urban development.

Therefore this research does not intend to identify which scenario is the most suitable for the city, nevertheless the idea was to develop a model that helped to visualize and analyse how the urban context of the city may unfold in the different situations according to its urban norms and different policies options implemented in order to understand the impact of the urban density in the development of the city.

The scenario evaluation shows that there still are contrasting elements between the scenarios: The compact development as the indicators shows the land consumption is reduced but the increase of the density in the already build up areas is to its maximum capacity, can cause a high level of congestion on the primary roads. The average of green urban areas in this scenario is low but this is because it was calculated with the same percentage that the city has now. In the other hand the sprawl development takes over all the vacant land that the city has projected causing an increase of distances between the different activities which will need a good transport system increasing the cost for the basic services of the entire city but as the city expands the average of green areas according to the actual percentage increases.

According to the findings of the literature review and the results of the evaluation, Sustainable Urban development is related to the urban density as the world is becoming more urbanized and the space consumption increases every year, the debate whether the design of a compact city or a sprawl city is the best path to follow stills have many questions opens.

One reasoning is that the city must be "…a form and scale appropriate to walking, cycling and efficient public transport, and with a compactness that encourage social interaction"(Elkin, et al., 1991).According to this concept the sustainable urban development does not have a unique and specific formula, it goes along with many elements of the context of the city as the scenario evaluation shows.

In conclusion urban sustainable development is a task of constant development that have a lot to do with the specific context of each city, and urban density is part of one of the elements that should be studied in order to achieve a better development. This urban development must have as many variables such as public transport policies, distribution of land uses, waste collection and so on in order to have more opportunities to manage and balance better the problems of the city.

10.2. Limitations.

For the development of collaborative scenarios due to the constraint of time of the fieldwork, only 11 persons were able to participated in the interviews, also just one interview per stakeholder was done and sometimes new ideas or topics appeared in later interviews that could be good to asked to the previous person.

For the development of the model the main constraint was the extent of the study area because in each process long hours have to be waited. In addition to that many assumptions have had to be made to operationalize the model such as:

There are many other factors that could be included in the model such as the variable of the population growth due to the economic situation of the city, or the analysis of the different typologies of family units according to the socio-economic status, or new policies about the land use distribution that will have an impact on the outputs of the land allocation and densification. Also the identification of special natural areas in the vacant land or consolidate urban area for its protections. All these were not been able to implement due to the lack of information and time constraint. (Explained in sections 6.6.3 and 6.6.4.)

Also in the 3D model step many simplifications have to be made like that all the buildings will be with the same design because the urban norm of the city is very flexible according to the design of the project.

For the evaluation of the scenarios, the analysis was made based on the data of the year 2009 and many assumptions were made in order to be able to quantify the different scenarios.

10.3. Recommendations.

In the collaborative scenario planning is important to have the participation of many stakeholders and from many different backgrounds because by participating more persons more ideas and topics will be to develop the scenarios. For the development and modelling process of the model socio economic data could help analyse better the relation of the different types of built-up areas and the urban density of the city. And analysis of the different typologies of buildings and trend of the development of the city would be useful for implementing the model with more details.

Santa Cruz de la Sierra is a city that has experience an explosive urban growth during the last 50 years where its footprint has growth in a 110%, this fast development of the city leave behind the Plan Techint - Master Plan of the city which never expected to growth this fast and the urban norms were settled for a small city. These situation have been going on for the last 20 years where the city growths faster than what the policies or any strategic plan can control.

The scenario development and evaluation of this research will help to visualize and understand the different alternatives that the city can have in the future base on different policies development and on the urban norm that the city has allowing to the decision makers to be more resilient to unexpected changes. The analysis of the urban norm helps to visualize how the city may unfold in the future and if it is a good policy or may need to be adapted base on the results of the different scenarios.

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