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Títol

Energy consumption and carbon dioxide emissions of the construction of six urban models.

Autor/a

Pol Adarve Panicot

Tutor/a

Pere Espelt Lleonart

Departament

Infraestructura del transport i del territori

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To my oncle Climent for his tireless dedication and patience.

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To Maca for her love.

To my tutor Pere Espelt, for his devotion and guidance.

ABSTRACT

Subject: sustainability modeling.

Key words: Urbanism, architecture, construction, energy, global warming.

A great deal of essays exists that quantify the energy consumption and carbon dioxide emissions of the building constructions. Others essays, much less, have quantified some either roadbeds or sidewalks of different materials. However, on the one side, it is incipient the generalization of buildings and infrastructures typologies. On the other side, some stages of the building and infrastructure life cycle receive greater attention (manufacture of the element materials, consume of the function during the life) than other such as the construction, which calculation is more complex.

It is presented a study about the energy consumption and emissions of the construction of different city models based on discernments and results of experiences of existing calculations. It is quantified the emissions and the non-renewable energy used directly or indirectly in order to transform, manufacture, transport and construction of the building structure, the road infrastructure, the drainage system, the seweage system, drinkable water and public lighting.

Subsequently, it is completed with the common values of the complete life cycle and the results are referred to conventional ratios: per habitant, per gross hectare, per square meter of building roof and home unity, with revealing results.

Due to it consists of contrasting different town-planning models, only it has been quantified the elements of the building structures (neither coatings nor finishing coatings nor installations of the building). In addition, because of the variability of the results depending on the materials chosen, it has considered common materials, with exception of those which are inherent of the own model (metallic structures of the block of the American downtown or reinforced concrete structure of the Asiatic city blocks and ex-soviet; prefabricated concrete sidewalks of European city and asphalt pavement sidewalks in American city). Other kind of infrastructure has been obviated for having topology modalities and costs very dependent on the regional cultures, such as the electricity energy infrastructure or the collective heating.

From the combination of different types of urban nets (reticular, concentric-ratio, lineal, fractal and organic), of the different types of blocks (closed, opened, permeable) and of edification (vertical and horizontal blocks, collective house, individual house between dividing walls, terraced house, semi-detached house or isolated house), the results are representatives of the places and the shapes of current town-planning reference cities.

It is considered the residential closed block extension and short blocks (Barcelona and Buenos Aires) and tall blocks(New York), the American downtown (Manhattan and Chicago), the isolated building extension (Rome and Barcelona), the residential low density suburbs of reticular type (Chicago, Paris and Tokyo), de lineal type (London, Barcelona and Los Angeles) and the fractal type (Miami, Atlanta and Washington); the functional residential horizontal blocks housing states of the East Europe countries (Berlin and Moscou) and of vertical blocks of the Asiatic metropolis (Abu Dabi, Hong Kong, Pekin), beside other models less generalized but interesting as the permeable blocks expansion Central Eupoean (Berlin and Munich) and the collective housing states of the Central Europe (Freiburg) and Asiatic (Shangai).

RESUMEN

Tópico: Modelización de la sostenibilidad

Área: Urbanismo, arquitectura, construcción, energía, calentamiento global

Existen abundantes trabajos que cuantifican el consumo energético y las emisiones en dióxido de carbono de la construcción de edificios. Otros trabajos, muchos menos, han cuantificado algunos firmes o aceras de diferentes materiales. No obstante, es incipiente la generalización a tipologías edificatorias y de infraestructura. Por otro lado, algunas etapas del ciclo de vida del edificio o la infraestructura reciben mayor atención (fabricación de elementos materiales, consumos de la función en vida) que otras etapas como la construcción, cuyo cálculo es más complejo. Se presenta un estudio sobre el consumo energético y las emisiones de la construcción de diferentes modelos de ciudad a partir de los criterios y resultados de experiencias de cálculo existentes. Se cuantifican las emisiones y la energía no renovable utilizada directa o indirectamente para transformar, fabricar, transportar y construir la estructura de la edificación, la infraestructura viaria, el alcantarillado, el agua potable y el alumbrado público. Luego se complementa con valores comunes del ciclo de vida completo y se refieren los resultados a ratios convencionales: por habitante, hectárea bruta, metro cuadrado de techo edificado y unidad de vivienda, con resultados reveladores.

Como se trata de contrastar distintos modelos urbanísticos, solo se han cuantificado los elementos de estructura edificatoria (no los cerramientos, acabados ni instalaciones de edificación). Por otro lado, debido a la variabilidad de los resultados según los materiales elegidos, se han considerado materiales lo más comunes posible, a excepción de aquellos que son inherentes al propio modelo (estructura metálica del bloque del downtown americano o estructura de hormigón armado del bloque de ciudades asiáticas y ex-soviéticas; acera de pieza prefabricada de hormigón en la ciudad europea o acera de pavimento asfáltico en la ciudad americana). Otro tipo de infraestructura ha sido obviada por tener unas modalidades de tipología y coste muy dependientes de la cultura regional, como la infraestructura de energía eléctrica o de calefacción colectiva.

A partir de la combinación de diferentes tipos de trama urbana (reticular, radioconcéntrica, lineal, fractal, orgánica), de tipo de manzana (cerrada, abierta, permeable) y de edificación (bloque vertical y horizontal, casa colectiva, casa individual entre medianeras, aparejada o aislada), los resultados son representativos de lugares y formas de ciudad referenciales del urbanismo actual. Se considera el ensanche residencial de manzana cerrada y bloque bajo (Barcelona, Buenos Aires) y de bloque alto (Nueva York), el downtown americano (Manhattan y Chicago), el ensanche de bloque aislado (Roma, Barcelona), los suburbios residenciales de baja densidad de tipo reticular (Chicago, París y Tokyo), de tipo lineal (Londres, Barcelona, Los Ángeles) y de tipo fractal (Miami, Atlanta, Washington); los polígonos residenciales funcionalistas de bloque horizontal de los países de Europa del Este (Berlín y Moscú) y de bloque vertical de las metrópolis asiáticas (Abu Dabi, Hong Kong, Pequín), además de otros modelos menos generalizados pero interesantes como el ensanche de manzana permeable centroeuropea (Berlín y Múnich) y los polígonos de casas colectivas centroeuropeas (Freiburg) o asiáticas (Shanghai).

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1 MATTER OF INVESTIGATION

The world's population, particularly in developed countries such as Europe, is moving from rural to urban areas. For instance, more than a quarter of European Union's territory has now been directly affected by urban land use; by 2020, roughly 80% of Europeans will be living in urban areas. As a consequence, the various demands for land in and around cities are becoming acute. On the day-to-day life, we all witness rapid, visible and conflicting changes in land use that are shaping landscapes in cities and surroundings as never before (European Environment Agency, 2006). Thereby, urban settlements are expected to increase in variety and size throughout this century taking land around them forcing agriculture to move outwards and in turn displacing forestry to smaller zones.

The reason to be of this master thesis arises from the problematic that bear urban settlements from an environmental impact approach. Urban areas are formed by a number of components that are not only very costly in economic terms, but also in environmental terms. The main part of the elements used to built cities need stunning amounts of raw materials and vast quantities of energy to be manufactured on both constructed 'in situ' and manufactured.

Foremost, the problematic appears since cities are complex, non repetitive containing a lot of different types of materials and are constructed by different methods. Therefore, there has always been abundant works that quantify the environmental impact of simple manufacturing products but much less in civil engineering elements that commonly are exclusive and not mass produced. Some works, have assessed several pavements or sidewalks made of different type of materials. However, there is barely research on the generalization of the building typologies and infrastructures. Additionally, some stages throughout the life cycle of products have already been matter of research (manufacture of material components, maintenance within the lifespan) leaving the construction works into an unexplored terrain. Looking at the material components themselves they can have an associated embodied environmental impact which can be calculated by the energy required to treat raw materials, the fuel needed for transport, plus energy consumed through the remaining processes until final product is got. In contrast, when it comes to assemble all the elements that compose cities it becomes a non-straightforward task to play around with different sets of components in order to find the optimal performance that optimize energy consumption, natural resources and urbanized land area.

Several researches have investigated in the field of the economy of cities reaching to some extent at similar outcomes. Nowadays, there is a worldwide consensus that dense urban areas provide economies of scale and accumulate wealth. On the other side, this consensus touches on the environment field which has been proved in a number of cases that dense urban areas and some structural typologies are more 'eco-friendly' than low-density ones. However, there is still a lack of reliable data of what building a city with all its elements really means and which the way to get the best performance is. Therefore, construction of cities and its functional elements requires very energy intensive processes and vast amounts of natural resources that have to be carefully analyzed.

It is in the 21th century that the current rate of population growth and in turn the increase in urbanized area to host those new citizens is threatening the environment and ecosystems. Thereby, the role of cities is playing a prime role in the current century where the trends are pointing to settle down in high dense areas. When it comes to find out the best performance in terms of population density, street layout, building typology and percentage of green areas among other features there is a non-clear consensus and there is still a long way for research.

2 OBJECTIVES

In order to develop properly the content of this paper it is crucial to state the aims to achieve. We could describe the aims of this project in two main groups. On the one side, the aim is to expand the knowledge in urban design going into details of the components and networks that cities are made of. Within this first group the goals are the understanding of the urban patterns that cities have adopted over history, the reason to be of different street layouts and building typologies and in an engineering level the comprehension of sizing and design of the city components to meet the functional and qualitative needs. On the other side, the so-called second main group within these objectives is framed in environmental impact assessment by means of the understanding of sustainable indicators such as energy consumption and carbon dioxide emissions due to the construction of cities and its materials. Finally, there is a point where these two main blocs get overlapped and the meaning of the results has to be analyzed and discussed properly.

Generally the operational goals we want to achieve by developing this master thesis can be summarized in the followings points:

1) Complement the knowledge on urban design, public infrastructure and service networks which cities are made of and compare different typologies worldwide.
2) Quantify by means of conventional environmental indicators -energy consumption and carbon dioxide emissions- the material manufacturing and construction stages of a selection of representative urban models.
3) Characterize the impact of the different typological factors (type of urban street layout, building morphologies, green open space, and infrastructure typologies) and discriminate the most important.
4) Interpret outcomes from a urban planner point of view and express them in urban parameters such as per inhabitant energy consumption and release of CO_2 and per square meter of built floor.
5) Be capable of discuss the sustainability in terms of energy consumption and emission of CO_2 of different urban patterns and building typologies regarding material manufacturing and construction stages.

3 THEORETICAL FRAME

3.1 Background and history

Sustainability is important and have became into the mainstream since its definition was established by the United Nations (UN) in the Johannesburg Declaration in 2002. The UN defines sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to meet their needs"* (United Nations, 2002). The current patterns of modern society based on material goods consumption constitute an unsustainable lifestyle, in terms of natural resources extraction, that compromise not only future generations but also the present and short-term planet's life. Nowadays, society's collective reliance on land and nature for food, raw materials and waste absorption results in a resource demand without precedent in history.

The design and construction of civil works have been traditionally driven for quality criteria, cost and deadlines that are no longer adequate to satisfy the demands of a *sustainable development*.

The environmental assessment will become, undoubtedly, in one of the fundamental processes in the decision-making of any productive sector that tries to frame within the sustainable principles. Particularly in the construction sector that requires vast amounts of raw materials and energy, and generates huge amounts of waste and release of greenhouse gases. With a contribution of 10% in the global economy, consume up to 40% of total energy production and contribute significantly on climate change (Energy Information Administration, 2008).

There is a worldwide consensus that current patterns of consumption and goods production, particularly in developed economies, are the main cause of Earth's environment degradation. However, additionally in the past two decades emerging economies such as the case of China, India and Brazil among others started to raise the levels of consumption and production with an overall amount comparable with western countries even though the per capita consumption is still low. The adoption sustainable monitoring, for instance, measuring changes in consumption patterns by establishing indicators, provide stakeholders with integrated variables of current and potential future trends giving information to respond with appropriate guidelines and regulations.

The highest levels of energy consumption, power generation and carbon dioxide emissions have been concentrated mainly in the United States, Japan and the European Union releasing up to 40 per cent of the global greenhouse gases emissions. In contrast, the last two decades have experimented astonishing rates of economic growth in developing countries, especially the very populated economies of east and south Asia. This event has turned now the highest rates of consumption to the emerging economies. As a result china has taken the lead in terms of carbon dioxide emissions exceeding any other country in the world though China's per capita emissions are still not comparable to any developed country (Rosen, D. H. and Houser, T., 2007).

The nature of the indicators themselves let us to quantify and compare between nations and regions providing a reliable monitoring tool that brings us the opportunity to export practices and/or polices from side to side. Implementing sustainable economic and social polices claims for a coordinated action of both stakeholders and public. Thereby, these indicators may be scientifically conducted but at the same time they must be intelligible and attractive for all the stakeholders involved.

The key points required for economic growth are energy, materials, forestry, water and land. Therefore, indicators are crucial for monitoring the use and evolution of these resources linking the consumption levels with environmental impact caused by the extensive extraction of them. Throughout history, different raw material have been used for power generation; from its early beginning of industrial revolution with wood and water, then coal, later petroleum and natural gas, and recently, to a significant extend, nuclear power.

Even though there have been initiatives and facts to implement energy efficiency in many sectors such as manufacturing, construction and transportation, these improvements are still far from resounding. Developed countries (particularly the industry sector) account about 60% of the global energy consumption although houses only 20% of the world's population. The most energy intensive sub-sectors are iron and steel, chemicals, petroleum refining, pulp and paper, cement, agriculture, construction and transport, although household consumption is also significant (Bentley, M. and Leeuw, B., 2000).

Recent trends in small-scale business of power generation seem to point towards renewable energy sources, even though there is still a long way to compete with current technologies that have fossil fuels as a main resource.

Energy is an indisputable engine of development. It will keep expanding in the developing world what will cause serious problems at local and global scale. Therefore, any effort towards energy optimization is a clear step forward to a more sustainable world.

3.2 Sustainability indicators

Over the past century many there have been movements of society and official organizations to quantify human impact on Earth and to try to set guidelines in any governmental level to regulate human development. The construction of urban settlements and public infrastructure in general have been traditionally governed by quality, cost and deadline criteria that are not enough anymore, to meet the requirements of a sustainable development. One tool to quantify the environmental impact of industrial products is the Environmental Impact Assessment (EIA) which brings us the interaction between the product at hand and the environment from "cradle-to-grave', and will become without a doubt, one of the studies of reference that should be conducted in any industrial product that is expect to be framed within the sustainable principles. Particularly, in the construction sector that requires great quantities of raw materials and energy, and produce large volumes of emissions and waste (Antequera, J. and Carrera, E., 2009).

In the path of trying to quantify the sustainability of any product or activity we need a proper tool to let us measure, compare and classify the different alternatives. Such tools that have been promoted over years are indicators which focus on a representative aspect of a process that describes a part of a whole. These indicators can be controlled by a sole variable (number of cars in a municipality) or by a group of them, for instance, the squares meters of urban green area per inhabitant, or finally, they can also be found interrelated composing complex indicators such as economic ones.

An indicator is a sign generally measurable which show us a quantitative or qualitative feature from which we may derive information of the past, the current situation or forecast the future of a system. Likewise, governmental regulations consist on set goals by means of such indicators which society has to strive for in order to achieve them and guide human beings towards a more sustainable development.

Some of the targets stated by United Nations (UN) to guide humanity towards sustainable development are, regarding to environmental issues, emission of greenhouse gases, consumption of ozone depleting substances, ambient concentration of air pollution in urban areas, among many other ones. And once again, we may appreciate here that we cannot deal with the entire problem but by using specific indicators we can concentrate on a concrete aspect that provides crucial guidance for decision-making in a variety of ways (United Nations, 2000).

Others similar targets are also the Johannesburg Plan of Implementation and the Commission on Sustainable Development (CSD) which encourage further work on sustainable indicators by countries and states specific conditions and priorities. Furthermore, the Chapter 40 of the Agenda 21 claims for the necessity to develop indicators for sustainable development by countries at the national level and governmental and non-governmental organizations at the international level (United Nations, 1992).

Within the European Union we may find a Core Set of Indicators (CSI) clustered in ten subjects (agriculture, air pollution, biodiversity, climate change, energy, fisheries, terrestrial, transport, waste and water) with the purpose of (1) providing stable and manageable basis for indicator reporting by European Environmental Agency (EEA), (2) prioritizing improvements in data quality from countries to European level, (3) streamlining contributions to other indicator initiatives, and (4) strengthening environmental dimension alongside economic and social dimensions (McGlade, 2004).

3.3 Indicators precedents and modeling of sustainable urban design

There are different indicators that adjust better than others to model the sustainability of a real fact and which have been supported more than others for official organizations and public. One of the most accepted so far has been a contribution by William Rees who establish a land area index to express the health of individuals, households, communities, cities and even the whole world. Rees provide a visual indicator called Ecological Footprint (EF) index that means the equivalent land area needed to sustain daily activities, absorb carbon dioxide emissions and the demand of terrestrial land and ocean surface for the extraction of raw materials and food. All Ecological Footprint Methods (EFM) developments so far have been based mainly in the first proposal by Rees and Wackernagel (1994) which is grounded in the principle that any energy or material consumption requires a certain land to be produced and assimilated back to the environment. Every type of consumption taken into account to calculate the EF is multiplied by the specific land need index and the total EF can be obtained by summing up footprints per separate. As Stoeglehner and Narodoslawsky (2008) argues in their work, the initial method has been criticized for: (1) the way the consumption is examined, (2) the inability of EF to take into account impacts such as toxicities and effect in ecosystems, and (3) the linked concept that footprinting has an anti-trade bias.

The shortcomings of the first model are, in theory, that the carbon cycle is neglected, i.e., burning fossil fuels entails release carbon stored in the lithosphere in different forms into the atmosphere in gas form. In order not to alter the environment, it cannot be emitted more gas in the atmosphere than the one phased back into the lithosphere. As Harrison (2003) notes in his study currently about 30 times more carbon is emitted in the atmosphere than what can actually be phased out in the lithosphere (Harrison, 2003).

Additionally, other indicators have been developed such as the energy consumption or release of pollutants as well. One of the pollutants of reference by the UN is the release of carbon dioxide or the so-called greenhouse gases GHG contributors to climate change and inextricable indicators of levels of fossil fuels consumption. The Energy Information Administration EIA describes GHG as chemical compounds found in the Earth’s atmosphere that let the sunlight enter freely but when the sunlight is radiated back into the space greenhouse gases absorb this infrared radiation and trap the heat leading into an increase of atmosphere’s temperature. Many gases have these properties in the atmosphere (water vapor, carbon dioxide, methane, and nitrous oxide), meanwhile others are directly manmade (certain industrial gases). Greenhouse gas emissions come basically from the combustion of fossil fuels in energy use. Energy use is largely the consequence of economic growth with short-term fluctuations in its growth rate created by weather patterns affecting heating and cooling needs in developed countries, as well as changes in the fuel used in electricity generation grid. For instance, energy-related carbon dioxide emissions, resulting from the combustion of petroleum, coal, and natural gas, represented 82% of total U.S. anthropogenic greenhouse gas emissions in 2006 (Energy Information Administration, 2008).

3.4 Calculation precedents and reference data

As is stated above there is no data found of embodied energy and carbon dioxide emissions of the construction of entire cities, although there is much more said of subcomponents of a city such as road pavements, sidewalks or buildings. For instance, in the international context, we may find a study titled *Development of a life cycle assessment tool for construction and maintenance of asphalt pavements* carried out by Huang et al. (2008) where these researchers developed a Life Cycle Assessment (LCA) of pavements in order to assess its environmental impacts. Huang et al. describe the development of a LCA model for the case of pavement construction and maintenance complemented by up-to-date research findings. One of the outstanding results is the production of hot mix asphalt and bitumen which is found to represent the most energy intensive process (Huang et al., 2008).

When it comes to building construction data, it is the field where more data have been found, especially on commercial buildings more than residential ones. The construction of buildings has a determining role on environmental threats through consumption of land, and raw materials and generation of waste. At the same time, it is a significant user of non-renewable energy and greenhouse gases emitter. While environmental issues become more and more important the energy consumption decreases and the efficiency increases over the lifetime of a building leading the construction stage impacts as a one of greater importance. A study titled *Energy and environmental indicators related to construction of office buildings* written by Dimoudi and Tompa (2008) collects data of embodied energy and the equivalent emissions of CO_2 and SO_2 in contemporary office buildings. It also stresses the importance of the embodied energy of the structure's building materials (concrete and reinforcement steel) which represents the largest component in the building's total embodied energy varying from 59 to 67% of the buildings examined in their study, while other components such as the building's envelope materials represents a lower but significant proportion of the building's total embodied energy. Another outstanding result of their study is that the embodied energy correspondence varies between 12.55 and 18.50% of the energy needed for the operation of an office building for over a 50 years life (Dimoudi, A. and Tompa, C., 2008).

Another item found to have reference data is concrete manufacture. Literature reviewed in this field is from a study titled *Green House Gas Emissions due to Concrete Manufacture* written by David et al. (2007). In that case the analyzed indicator is the carbon dioxide emission released on all the stages that concrete passes through to get a final product. The CO_2 emissions are often used as an index to compare the environmental impact of different construction materials in Environmental Sustainable Design (ESD). The issues of environmental impacts of concrete production have become important since many major infrastructure owners are now requiring ESD. In this study, portland cement is found to be the main source of CO_2 emissions generated by typical commercially produced concrete mixes, being responsible for 74 to 84% of the total CO_2 released. The next major source of CO_2 emissions in concrete are coarse aggregates, being responsible for 13 to 20% of total CO_2 emissions founded in the use of electricity. Blasting, excavation, hauling and transport comprise less than 25%. While the explosives have very high emission factors per unit mass, they contribute very small amounts (<0.25%) to coarse aggregate production, since only small quantities are used. Production of a tone of fine aggregates generates 30 to 40% of the emissions generated by the production of a tone of coarse aggregates. Fine aggregates generate less equivalent CO_2 since they are only graded, not crushed. Concrete batching, transport and placement activities contribute all of them very small amounts of CO_2 to total concrete emissions (Flower, D.J.M. and Sanjayan, J.G., 2007).

3.5 Energy and CO_2 emissions as a indicators of reference

All the elements that compose an urban settlement and that are part of a building project have related an environmental impact due to of the building materials and the installation process. Therefore, the aim of this chapter is quantify the environmental load embodied in the different urban settlement alternatives.

In order to achieve that, this paper focuses on the energy consumption and release of CO_2 gases throughout those processes. Other factors involved in such a process but omitted in this work due to the small contribution at the overall problem and because are much more difficult to assess are the embodied energy and CO_2 emissions of leftover material in the execution stage and for packaging materials.

In contrast, what will be the main focus in the present thesis is the energy consumption in the manufacturing process of the building materials and the energy consumption required for the machinery and human beings for the execution stage.

Additionally these process mentioned above bear associated an emission of polluting gases being the gas of reference studied here the carbon dioxide. Therefore, the assessment of CO_2 emissions will be reduced at the manufacturing of materials and the CO_2 released by the machinery through the installation process.

The embodied energy and CO_2 emissions have been broken down into two differentiated groups in the following sections which are the materials manufacturing phase and the construction or installation one.

3.5.1 *Embodied energy and embodied CO_2 emission of materials manufacturing phase*

Every finished product in our case for construction materials have to go through different stages to be finally conformed. Initially there is an environmental load associated at the elaboration of the products necessary for our construction at hand. Even though it is true that many of the composing elements of urban infrastructure have to be assembled at the building place requiring a substantial amount of energy there are some very energy intensive processes to elaborate these construction materials such as the manufacture of concrete and steel molding among others.

Different researches label the energy required to produce any product as embodied energy. For instance, as Braid and Chain (1983) argues in their paper, embodied energy is the energy consumed in all activities necessary to support a process, and comprises both direct and indirect components. Thereby, embodied energy can be summarized as the energy initially destined for materials manufacturing.

Additionally, such processes usually very energy intensive bear associated a release of CO_2 emissions whatever it is in the electricity mix due to the use of fossil fuels, the use of carbonaceous materials through the process itself or the transportation of the raw materials from the quarry to the fabric if it’s the case. Some researchers have driven their efforts to quantify the CO_2 emissions of building materials (Nässén et al, 2006; Flower and Sanjayan, 2007).

3.5.2 *Embodied energy and embodied CO_2 emission of construction process*

As it is stated previously urban infrastructure altogether with buildings requires frequently very energy intensive processes to assemble all the components at the construction place by using sometimes a broad range of means (e.g. from manpower to the most advanced technology). This especial characteristic of the urban infrastructure is due two main reasons. First because commonly each infrastructure is unique and exclusive and seldom times we find two identical infrastructures, on the one hand, because of the random topography and geometry of each location, and on the other hand, because culture, economy and technology differs from one to another region. The second main reason is that public infrastructures are usually large elements not feasible of mass production and due to its dimension it is not possible the manufacture in the industry and afterwards its transportation to the construction place.

Thereby, it is crucial in the Environmental Impact Assessment to take into consideration both the energy consumption and CO_2 emission in the construction process in order to achieve a reliable and representative analysis.

4 METHODOLOGY

4.1 Life Cycle Assessment

The Life Cycle Assessment (LCA) methodology permits the assessment of all environmental impacts associated with a product, process or activity by accounting and evaluating resource consumption and emissions (ISO - International Organization of Standardization, 2000). Civil engineering and the built environment are fields of great potential for LCA, and research in these areas may provide useful information for the ecodesign of the cities of the future. This approach implies the need for environmental data of the urban elements in order to take the best design decisions. However, there is still lack of information in life-cycle assessments in terms of environmental impacts of many urban elements. In order to face the global environmental threats, it is necessary to use Life Cycle Thinking to improve the design of cities, and so, introduce this information into the decision making process.

Urban settlements are composed of many different elements. Each one of them goes through several stages during their life span, although none of which are straightforward to analyze and quantify from an environmental perspective. From the early beginning of its conception to the final stage of recycling, demolition or dismantling there are many processes that have to be taken into consideration. These constitute transportation to site, construction and installation, lifetime operation of buildings and public services, repairs and maintenance. In a few words, a full Life Cycle Assessment (LCA) is required to properly understand and projects any product from an environmental point of view.

Since sustainable development has become into mainstream, a broad range of indicators have been raised to measure, compare and classify environmental impacts. However, in the field of civil engineering and construction, frequently researches have resort to energy as the indicator of choice. In contrast, even though the operational energy represents a remarkable amount of energy within the life span of a dwelling, it is relatively simple to assess (e.g. electricity bills). Therefore, embodied energy assessments have been focus of research due to its direct dependency on resources consumption, environment pollution and global warming.

Recently, other studies have stated that CO_2 emissions can be a more meaningful indicator of the overall environmental load. Frequently, CO_2 emissions might be derived from energy data, depending on the energy mix of a country or region and the chemicals releases of greenhouse gases. Thereby, this study focuses on both, energy uses and CO_2 emissions throughout the differentiate stages in the lifetime of the composing elements of an urban settlement:

- Initial production of the building materials
- Construction of buildings and street infrastructure
- Operation of the buildings and public services (mainly in terms of its energy use)
- Refurbishment and maintenance of building materials over the component's effective life
- Demolition and dismantling of buildings and street infrastructure
- Disposal of the waste materials at end of life

Due to the scope of this thesis it focuses in the first two stages; initial production of the building materials and the construction of buildings and street infrastructure.

4.2 Model of Analysis

The current work focuses its main task on the analysis of each urban model chosen. The procedure to follow starts from a selection of study cases (described in the section *5.1. selection of the study cases* of this paper). The next step is to design and size the public infrastructure and the number of floors of each building and its frame structure of each model regarding functional and operational criteria. It has been included the expected most energy consuming elements and most material requiring public networks of a typical urbanized land. Although it is very difficult to take into consideration all the elements of each model chosen is expected to be reliable enough due to the smaller contribution of the remaining elements and networks not considered.

On the one hand, the components taken into consideration in this study have been, regarding public infrastructure the roadway, sidewalks, drainage system, sewage system, drinking water system, lighting and street trees. On the other hand, when it comes to build-up land, it has been considered earthworks, building foundations and building's frame structure.

Once all the components are designed and sized it is time to measure them and put them in the calculation software (described in the section 4.4. calculation method of this paper) which will provide us with the corresponding results. In general terms the steps followed to develop this thesis are collected in the diagram below.

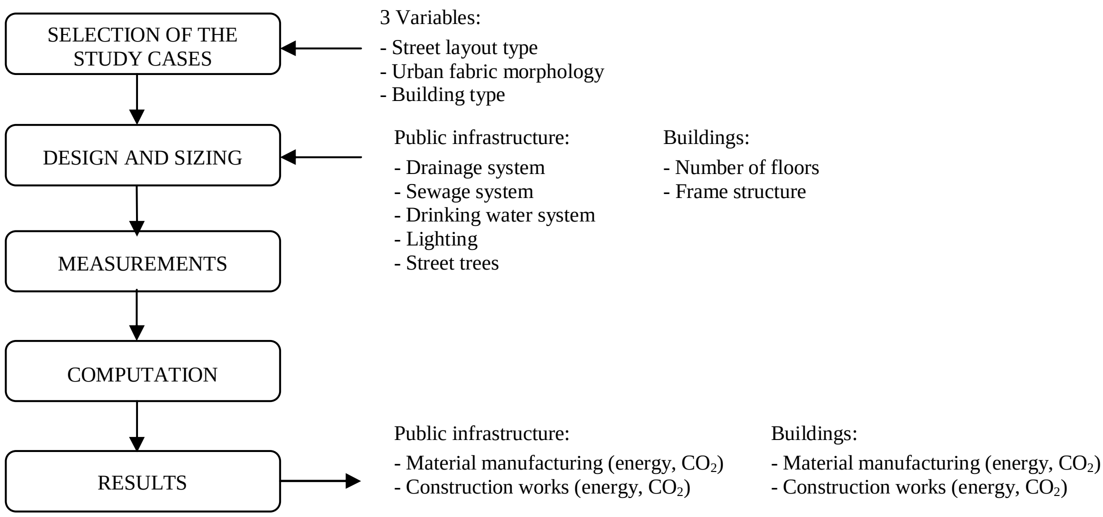


FIGURE 1. Methodology cycle followed for the present study. Source: Own creation.

4.3 Analysis model and adopted indicators

The six studied models have been introduced in the last section by showing first the so-called inspiring pattern altogether with the designed model. The finality of the designed model is to create an ideal case study with all the most representative energy intensive networks and components to make work an urban area of these dimensions. On the one hand, because it is not within our reach to figure out the real components and networks that composes each case. And on the other hand, because we have had to replicate unitary elements in order to homogenize project areas and compare among them. Another reason for that simplification is because in that way we are capable to charge equally the high-transport of each.

The indicators of reference used in this study are the energy consumption and the carbon dioxide emissions throughout two stages. The first stage is during the manufacture of the components such as cement, asphalt, pipelines, etc. where is needed, for instance, energy to run the machinery and fuel for transport, taking both into account when it is manufactured in the industry or 'in situ'. The second stage, of which there are fewer studies, is during the installation and the assembling of these components, normally at the work site.

4.4 Calculation method

The calculation method used in this study has been by means of the Catalan software *Time Control and Quality* TCQ, and particularly with the module of *Environmental Management* of the same software (TCQGMA). The process consists in choosing the items that will permit the complete installation of the infrastructure and putting in the item measurements.

The next sections are thought to describe the civil work items (civil works and materials) taken into account to build each infrastructure network and buildings. It is important to mention that in the following sections there are all the materials and processes to accomplish the final infrastructure, however, the variants of thicknesses and material combination used in each pattern are described later on in the chapter *6.4.Street section* of this paper. Additionally, it is worth to note that the items are arranged in function of what would be its executive process.

4.4.1 *Definition of public infrastructure constructive items*

4.4.1.1 Composing items for the roadway construction

In this section it is explained the items necessary to build up the pavement structure of a roadway. Overall, the items taken into consideration to build a road are the digging works and preparation of the road surface. The remaining soil it is shifted to an authorized facility. Once the terrain is suitable the pavement structure is built, first installing the subbase course with graded-aggregate, then the base course of gravel-cement and finally the wearing course. The items taken into account to accomplish the road structure are:

NUM.	ITEM
I	Dig and soil load by mechanic means
II	Transport of spare soil to an authorized facility by a 20 t truck, with a route from 15 up to 20 km
III	Check and compaction at 95% of Modified Proctor
IV	Subbase course of graded-aggregate and compaction at 95% of Modified Proctor
V	Base course of gravel-cement and compaction at 98% of Modified Proctor
VI	Prime coat with anionic bitumen emulsion, with irrigation requirement of 1.5 kg/m2
VII	Pavement of hot mix asphalt of semi dense composition with calcareous aggregate and asphaltic bitumen of penetration, spread out and compaction at 96% of Marshall test
VIII	Tack coat with anionic bitumen emulsion, with irrigation requirement of 1 kg/m2
IX	Pavement of hot mix asphalt of dense composition with calcareous aggregate and asphaltic bitumen of penetration, spread out and compaction at 96% of Marshall test

TABLE 1. Composing items for the roadway construction.

4.4.1.2 Composing items for the sidewalk construction

The civil works carried out to build a conventional sidewalk are, first of all, the soil adaptation and load of the remaining one to a truck to be shifted to a proper facility. Then, as the last common process considered in this study there is the base course installation, normally of recycled aggregate. Next we have considered two variants of sidewalks. The first type is finished with a pavement of mass concrete, while the other one with a layer of hot mix asphalt. Finally, two types of kerb has been considered, one made of mass concrete and another one of granite rock.

NUM.	ITEM
I	Dig and soil load by mechanic means
II	Transport of spare soil to an authorized facility by a 20 t truck, with a route from 15 up to 20 km

III	Check and compaction at 95% of Modified Proctor
IV	Base course of recycled aggregate and compaction at 98% of Modified Proctor
V.i.	Pavement of mass concrete of soft consistency, maximum aggregate size of 20 mm, and spread out by mena of a truck
V.ii.	Pavement of hot mix asphalt of semi dense composition with calcareous aggregate and asphaltic bitumen of penetration, spread out and compaction at 96% of Marshall test
VI.i.	Straight kerb of concrete pieces, installed over concrete base of 25 to 30 cm high and jointed with mortar
VI.ii.	Straight kerb of granite pieces, cut off with mechanic saw, installed over concrete base of 25 to 30 cm high and jointed with mortar

TABLE 2. Composing items for the sidewalk construction.

4.4.1.3 Composing items for the drainage system construction

To build the drainage system considered as a lineal structure, it has to be dig until the requiring depth, normally a drainage pipeline cannot be nearer to the surface less than 1.4 meters. Once, the pipeline it has been installed in the bottom of the trench there are two backfilling materials, a sand covering layer and a backfilling with soil extracted from the excavation itself. Finally other components composing the drainage system and considered for this study are, the gutters as inlets for rainwater and manholes for maintenance works.

NUM.	ITEM
I	Dig of trench up to 4 m depth and 2 m width, on non-classified soil, by mechanic means
II	Backfilled with sand and trench compaction by vibrator tamper
III	Backfilled with material from the excavation and trench compaction by vibrator tamper at 95% of Modified Proctor
IV	Transport of spare soil to an authorized facility by a 20 t lorry, with a route from 15 up to 20 km
V	PVC pipe of 200 mm of nominal diameter
VI	Concrete pipe of nominal diameters of 400, 500, 600, 800, 1000, 1200, 1400, and 1600 mm
VII	Concrete box for gutter of 70x30x85 cm with walls of 15 cm thick over concrete base of 10 cm thick
VIII	Frame and practicable net for gutter made of foundation steel of 800x364x50 mm and 50 kg of weight
IX	Concrete support for manhole of 15 cm thick and 1,15x1,15 m of base dimension
X	Wall for square manhole of 85x85 cm, of 14 cm thick of perforated brick made at site
XI	Frame and lid for manhole of D=70 cm made of foundation steel

TABLE 3. Composing items for the drainage system construction.

4.4.1.4 Composing items for the sewage system construction

The sewer system execution is quite similar to the drainage one. The only difference entails the diameter pipes, which are normally lower than the drainage piping because of its lower peak flows.

NUM.	ITEM
I	Dig of trench up to 4 m depth and 2 m width, on non-classified soil, by mechanic means
II	Backfilled with sand and trench compaction by vibrator tamper
III	Backfilled with material from the excavation and trench compaction by vibrator tamper at 95% of Modified Proctor
IV	Transport of spare soil to an authorized facility by a 20 t lorry, with a route from 15 up to 20 km
V	PVC pipe of 200 mm of nominal diameter
VI	Concrete pipe of nominal diameters of 300,400, and 500 mm
VII	Concrete box for gutter of 70x30x85 cm with walls of 15 cm thick over concrete base of 10 cm thick
VIII	Frame and practicable net for gutter made of foundation steel of 800x364x50 mm and 50 kg of weight

IX	Concrete support for manhole of 15 cm thick and 1,15x1,15 m of base dimension
X	Wall for square manhole of 85x85 cm, of 14 cm thick of perforated brick made at site
XI	Frame and lid for manhole of D=70 cm made of foundation steel

4.4.1.5 Composing items for the roadway construction.Composing items for the drinking water system construction

The drinkable water system execution is similar to the drainage one as well. The only difference relies on the hydrant typologies. It has been considered two types of fire hydrants. One installed underground in a hatch while the other one is installed on the surface with a column form.

NUM.	ITEM
I	Dig of trench up to 4 m depth and 2 m width, on non-classified soil, by mechanic means
II	Backfilled with sand and trench compaction by vibrator tamper
III	Backfilled with material from the excavation and trench compaction by vibrator tamper at 95% of Modified Proctor
IV	Transport of spare soil to an authorized facility by a 20 t lorry, with a route from 15 up to 20 km
V	Inspection hatch of 38x38x55 cm, with concrete walls of 15 cm thick and base of perforated bricks, over sand bed
VI	Frame and lid for inspection hatch, of foundation steel of 420x420x40 mm and 25 kg of weight
VII	Gate valve with thread, of nominal diameter of 1"1/2, of 10 bar of nominal pressure, made of copper
VII.i.	Hydrant buried with hatch, with an outlet of 70 mm of diameter
VII.ii.	Wet column hydrant, with an outlet of 70 mm of diameter

TABLE 4. Composing items for the drinking water system construction.

4.4.1.6 Composing items for the lighting net installation

The lighting is installed, first by connecting an energy supply network with its electric cables and inspection hatches. Once the ducting net is adapted the lamp-posts can be placed with its luminaries. Finally to mention that, different power luminaries have been considered ranging from 70, 100, 150 to 250 watts and as well as different lamp-post heights and typologies as it is described in the table below.

NUM.	ITEM
I	Dig of trench up to 4 m depth and 2 m width, on non-classified soil, by mechanic means
II	Backfilled with sand and trench compaction by vibrator tamper
III	PVC duct of corrugated pipes of diameter 80 mm and covering mass concrete of 30x20 cm
IV	Copper duct, single pole of 1x35 mm2 of section
V	Copper duct, four poles of 3x16 mm2 + 10mm2 of section
VI	Steel earth connection with cover of 300 μm thick, of 1500 mm long and 14,6 mm of diameter driven into the ground
VII	Symmetric High Pressure Steam Sodium Lamp HPSSL of 70, 100, 150, 250 w
VII.i.	Lamp-post in form of truncated cone of galvanized steel sheet, of 6,8, and 10 m high and 1,5 m of projection, of a flat lamp bracket made of steel and with door, installed over concrete dice
VII.ii.	Lamp-post of column of galvanized steel in form of truncated cone of 3 and 6 meter high

TABLE 5. Composing items for the lighting construction.

4.4.1.7 Gardening and street trees planting

To plant the street trees it has been considered the natural soil to fill the pit. For gardening, the seeding task has been taken into account with the first harvesting work. For the street trees the planting process it is carried out by mechanic means. And finally mention that four different tree species have been taken into consideration in function of geographical location.

NUM.	ITEM
I	Natural soil for gardening of low quality spread out by medium backdigger
II	Seeding for grass of standard type, by manual means in a slope of less than 30% and first harvesting
III	Tree planting and pit excavation of 100x100x80 cm by mechanic means
IV	Tree grating of 106x106 cm and 25 cm deep, with four pieces of concrete with beveled edge
V.i.	Suplly of Alnus Glutinosa
V.ii.	Suplly of Pyrus Communis
V.iii.	Suplly of Platanus Hispanica
V.iv.	Suplly of Koelreuteria Paniculata

TABLE 6. Composing items for the street trees planting.

4.4.2 *Definition of private building constructive items*

4.4.2.1 Earthworks for basements and foundations

The civil works considered for basement and foundation digging are in first place the site adaption and leveling by clearing the vegetation. Secondly, the basement excavation by mechanic means, and finally, the transport of the remaining soil to an authorized facility.

NUM.	ITEM
I	Cleaning and clearing of vegetation with mechanical means and mechanical load over truck
II	Soil excavation to empty of the basement, up to 6m depth, in compact soil, with mechanical means and mechanical load over truck
III	Excavation of trenches and wells up to 1,5m depth, in compact soil, with mechanical means and mechanical load over truck
IV	Soil transport and legal disposal of the wastes using 20t trucks and for the load with mechanical means, with a travel from 10 until 15km

TABLE 7. Composing items for the earthworks execution.

4.4.2.2 Composing civil works for foundation and shear walls execution

The foundations have been considered of two types; continuous and isolated footing. Moreover, when the footing dimensions are so large than become overlapped a concrete slab foundation has been adopted. Finally, the shearing walls have been placed on the basement perimeter to support horizontal loads due to the soil pressure and vertical loads through the building structure.

NUM.	ITEM
I	Cleaning and ground leveling layer, 10cm thick, of mass concrete, plastic consistency and maximum size aggregate of 40mm, spilled from truck
II	Trench foundations of reinforced concrete spilled with pump, reinforced of 30 kg/m3 steel in corrugated bars with a quantity of 60 kg/m3
III	Reinforced concrete wall, to cover, with a quantity of reinforcement of form 10 m2/m3, concrete spilled with pump and steel in corrugated bars with a quantity of 60 kg/m3
IV	Reinforced concrete pavement of plastic consistency and maximum size aggregate of 10mm, spread through pump, mechanical run and vibrated, mechanical toweled adding 7 kg/m2 of grey quartz dust
V	Electrically welded mesh of corrugated steel bars, site made and manipulated in workshop, for the reinforcement of concrete pavement
VI	Concrete for raft foundations of soft consistency and aggregate maximum size 20mm, spilled using pump
VII	Steel in corrugated bars of elastic strain strength greater than 500 N/mm2 to reinforce slabs
VIII	Timber plank used for raft foundations

TABLE 8. Composing items for foundation and shear walls construction.

4.4.2.3 Composing items for frame structure construction

There has been taken into account two main types of frame structure; one made of reinforce concrete and another one made of timber. The frame structure is composed by pier as vertical faces while the horizontal supports are made of reinforced concrete slabs. Additionally, the timber frame structure contains basically timber beams and piers, finished by a timber truss.

NUM.	ITEM
I.i.	Reinforced concrete pile with form to cover and a quantity of 13,3 m2/m3, concrete spilled using cupola and steel in corrugated bars with a quantity of 120 kg/m3
I.ii.	Fir timber pile planed, section from 14x14 to 20x20cm and 4m length, made in workshop and treatment of copper salts in retort for profound protection, assembled over supports
II.i.	Reticular ribbed framework of 35+5 cm, with a quantity of 0,61m2 of mortar box of cement/m2 of framework, distance between axes 0,8m, and a quantity of 20kg/m2 of steel in corrugated bars for reinforced, steel in electrically welded mesh of 15x15 cm, 5x5 mm de diameter and 0,187 m3/m2 of reinforced concrete spilled using cupola
II.ii.	Fir timber pile planed, section from 10x20 to 14x24cm and 5m length, made in workshop and treatment insecticide and fungicide for medium protection, assembled on construction site over steel or timber supports
III.i.	Reticular ribbed framework of 25+5 cm, with a quantity of 0,61m2 of mortar box of cement/m2 of framework, distance between axes 0,8m, and a quantity of 20kg/m2 of steel B 500 S in corrugated bars for reinforced, steel in electrically welded mesh of 15x15 cm, 5x5 mm de diameter and 0,148 m3/m2 of reinforced concrete spilled using cupola.
III.ii.	Form for fir timber purling plane finished, section from 9x18 cm and 5m length, made in workshop and treatment insecticide and fungicide for all kind of superficial protection, 50 cm separation between axes and
IV	Inclinator reinforced concrete slab 15 cm thick, with form to cover, with a quantity of 1 m2/m2, reinforced concrete spilled using pump and steel in corrugated bars with a quantity of 15 kg/m3

TABLE 9. Composing items for frame structure construction.

4.5 Reference data sources

Energy data in this thesis have been obtained from the Energy Agency Administration which provides us not only statistics but also analysis on resources, supply, production and consumption for all energy sources (Energy Information Administration, 2008).

The data from specific building materials has been taken, in the case of asphalt from the Huang et al. with their publication on Life Cycle Assessment of asphalt pavements (Huang, Y., Bird, R. and Heidrich O., 2008), while the concrete data has been looked up in the work of David and Jay titled *Greenhouse gas emissions due to concrete manufacture* (David, J. M.F. and Jay G.S., 2007).

Regarding building energy consumption due to its construction the literature reviewed has been on Nässen et al. with their paper *Direct and indirect energy use and carbon emissions in the production phase of buildings: An input–output analysis* (Nässen et al., 2006), and finally, Dimoundi and Tompa for energy indicators data of buildings (Dimoudi, A. and Tompa, C., 2008).

The reference of civil works processes has been taken basically from the Catalan Construction Technology Institute ITeC by means of the TCO software. The ITeC has passed successfully the demands of The European Organization for Technical Approvals which affects the construction products.

5 CHARACTERIZATION OF THE URBAN MODELS

5.1 Selection of the chosen urban models

In the current section, the aim is to select representative models that can be used for further developments based on past experiences. Within the literature of urban morphology we may find authors such as the recognized author Kevin Lynch who suggested for first time a four category of urban patterns: capillary, radial, rectangular and free pattern (Lynch, K., 1954). While half century later, other authors such as Stephen Marshall classify urban patterns in five groups. The first three categories, regarding to Marshall are the grid, radial and linear forms. Additionally, there is a fourth category relating to tree-like and tributary layout, and finally, any other type of pattern would be clustered into the fifth ‘hybrid’ category (Marshall, 2005).

Urban morphology is a complex field where characterize street layouts is not straightforward, for that reason, we have established a set three variables of analysis. Those are the typology of the street layout, the morphology of the urban fabric, and finally, the building type.

The next step followed has been a search of real cases worldwide according the criteria explained above. The result of combining these variables is a search of 14 representative samples shown in the following table.

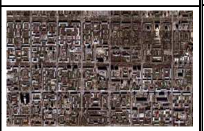
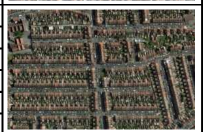
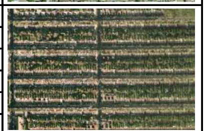
1	**Street layout**		grid	
	Urban fabric		closed	
	Main use		tertiary	
	Buildings	***Type***	high block	
		ordination	street aligned	
	Sample		CBD New York (USA)	
2	**Street layout**		grid	
	Urban fabric		open	
	Main use		tertiary	
	Buildings	***Type***	high block	
		ordination	isolated	
	Sample		CBD Los Angeles (USA)	
3	**Street layout**		grid	
	Urban fabric		closed	
	Main use		residential	
	Buildings	***Type***	high block	
		ordination	street aligned	
	Sample		Midtown Manhattan (USA)	
4	**Street layout**		grid	
	Urban fabric		open	
	Main use		residential	
	Buildings	***Type***	high block	
		ordination	isolated	
	Sample		Hong kong (China)	
5	**Street layout**		grid	
	Urban fabric		open	
	Main use		residential	
	Buildings	***Type***	horizontal block	
		ordination	isolated	
	Sample		Moscow (Russia)	
6	**Street layout**		grid	
	Urban fabric		closed	
	Main use		residential	
	Buildings	***Type***	low block	
		ordination	street aligned	
	Sample		Barcelona (Spain)	
7	**Street layout**		grid	
	Urban fabric		open	
	Main use		residential	
	Buildings	***Type***	multifamily	
		ordination	isolated	
	Sample		Freiburg (Germany)	
8	**Street layout**		grid	
	Urban fabric		permeable	
	Main use		residential	
	Buildings	***Type***	multifamily	
		ordination	street aligned	
	Sample		Munich (Germany)	
9	**Street layout**		grid	
	Urban fabric		closed	
	Main use		residential	
	Buildings	***Type***	detached houses	
		ordination	street aligned	
	Sample		Bristol (UK)	
10	**Street layout**		grid	
	Urban fabric		closed	
	Main use		residential	
	Buildings	***Type***	Detached houses	
		ordination	isolated	
	Sample		Sindney (Australia)	
11	**Street layout**		grid	
	Urban fabric		open	
	Main use		residential	
	Buildings	***Type***	detached houses	
		ordination	isolated	
	Sample		Chicago (USA)	
12	**Street layout**		linear	
	Urban fabric		closed	
	Main use		residential	
	Buildings	***Type***	attached houses	
		ordination	street aligned	
	Sample		London (UK)	
13	**Street layout**		linear	
	Urban fabric		open	
	Main use		residential	
	Buildings	***Type***	detached houses	
		ordination	isolated	
	Sample		Alexandria (Egypt)	
14	**Street layout**		fractal	
	Urban fabric		open	
	Main use		residential	
	Buildings	***Type***	detached houses	
		ordination	isolated	
	Sample		San José CA (USA)	

TABLE 10. Samples result of the research classified for the typology of the street layout, morphology of the urban fabric, and building type. Source: own creation.

Once examined all the combinations of the three variable of analysis we have to decide in which cases we will focus. Due to the scope of this thesis only six cases have been analyzed deeply. The criteria have been to look for the maximum difference between them in order to get sounding outcomes. The process of selection has been fixing one variable and using another one as a discriminator. For instance, fixing the urban fabric variable we find that Midtown Manhattan (sample number 3) and Barcelona (sample number 6) both have closed typology. In that case, the discriminative variable is the street layout in which one combination is rectangular grid while the other one is grid iron. Secondly, by fixing the variable urban fabric again, but now focusing on open typology we find Hong Kong (sample number 4) and Moscow (sample number 5) belonging to this group. Here the discriminative variable is the building typology finding the vertical block typology in the first one and horizontal block typology in the second one. And finally, the process to choose the last two samples we may fix the variable building typology. Here we find Suburban Chicago (sample number 11) and Los Angeles (Sample number 14) that both have detached house typology. The discriminative variable here is the street layout that in Suburban Chicago is characterized by rectangular grid while in Los Angeles it responds to a tree-like or fractal typology.

The Table below shows the six chosen samples. As we will come back later on these samples have been generalized in its representative urban patterns. Furthermore, for simplicity we state a code for each pattern that we will use to refer to them from now on. Finally, the red cells means the fixed variables while the green cells the discriminative ones.

Pattern	Code	Sample	Variables		
			Street layout	Urban fabric	Building typology
American Closed Fabric	A1	Midtown Manhattan New York (U.S.A.)	rectangular grid	closed	apartment
European Closed Fabric	A2	Eixample Barcelona (Spain)	gridiron	closed	apartment
Vertical Block Open Fabric	B1	Taikoo Shing Hong Kong (China)	grid-like	open	Vertical block
Horizontal Block Open Fabric	B2	Metropolitan Moscow (Russia)	tree-like	open	horizontal block
Rectilinear Detached Houses	C1	Suburban Chicago (U.S.A.)	rectangular grid		detached houses
Fractal Detached Houses	C2	Orange Los Angeles California (U.S.A.)	fractal		detached houses

TABLE 11. Chosen models with the fixed (red cells) and discriminative (green cells) variables.

5.2 Description of the chosen models

5.2.1 *American closed fabric*

The *American closed fabric* model is a very common pattern with a typical rectilinear street layout. We may find, for instance this pattern on the upper east side of Manhattan Island in New York. The urban fabric has a rectangle shape with and inner private backyard and blocks located over the perimeter. Regarding the roadway, there are two categories, avenues and streets of different width and functionality. Next, we may find two pictures. On the left side, one corresponding to a satellite view of a stretch of Midtown Manhattan in New York (USA), and on the right side the equivalent designed model with the land uses distribution.

The buildings have two different heights. At the avenues, the height constraint is higher and we have adopted an average of 10 floors plus three basements while in the streets there are 5 floors plus 1 basement.

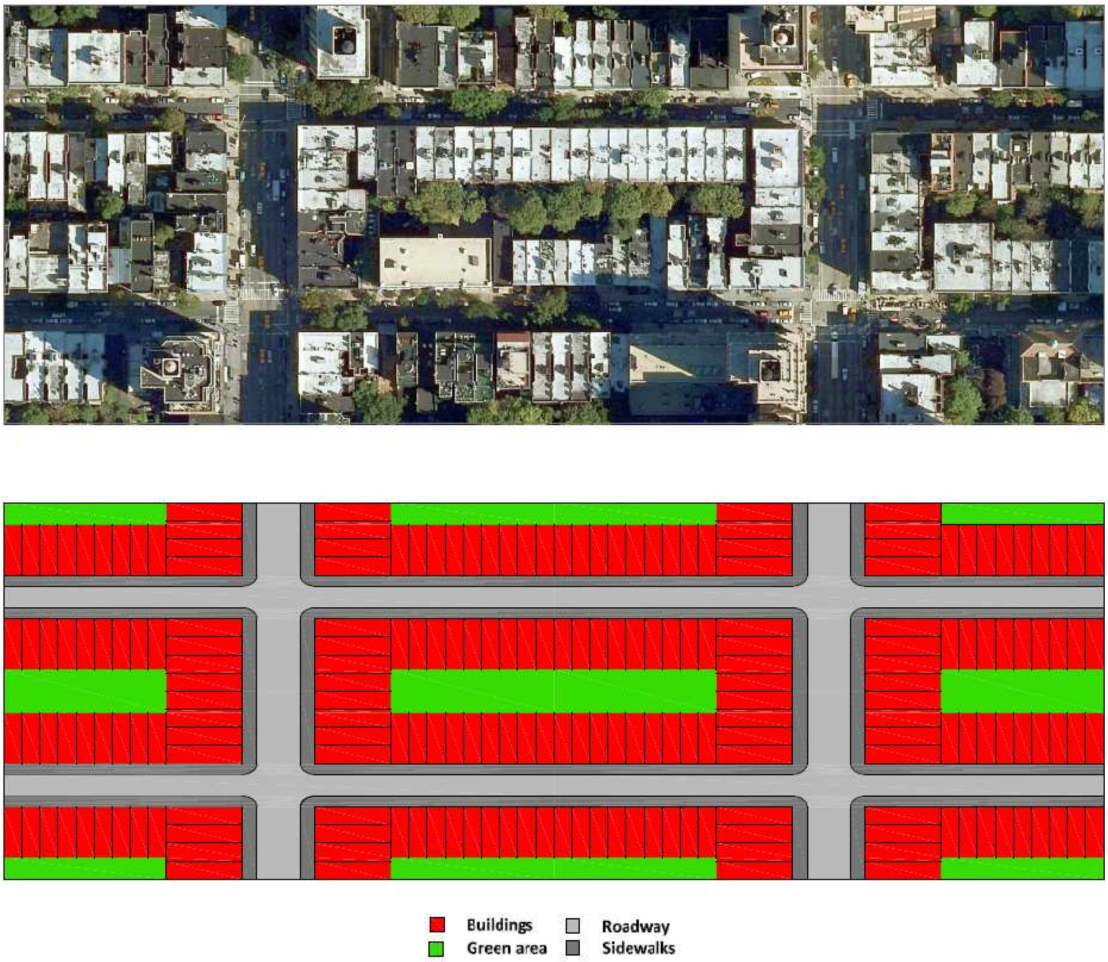


FIGURE 2. Plan view of Manhattan and the elemental unit of the A1 model. Land use distribution map. Scale 1/3000. Source: Own creation.

5.2.2 *European closed fabric*

The *European closed fabric* model belongs to a typical street layout of European cities. The inspiring example in that case is the Eixample of Barcelona developed by the urban planner Illdefons Cerdà. As in the case above, Cerdà foresaw an inner backyard for recreational purposes and blocks over the perimeter. The streets in that case are all with the same features giving a homogeneous rectilinear arrangement. Below are shown, on the left side, a satellite view of the Eixample of Barcelona (Spain) and, on the right side the equivalent created model with its land uses.

Regarding the building sizes, there is a homogeneous height of 6 floors plus two basements on average.

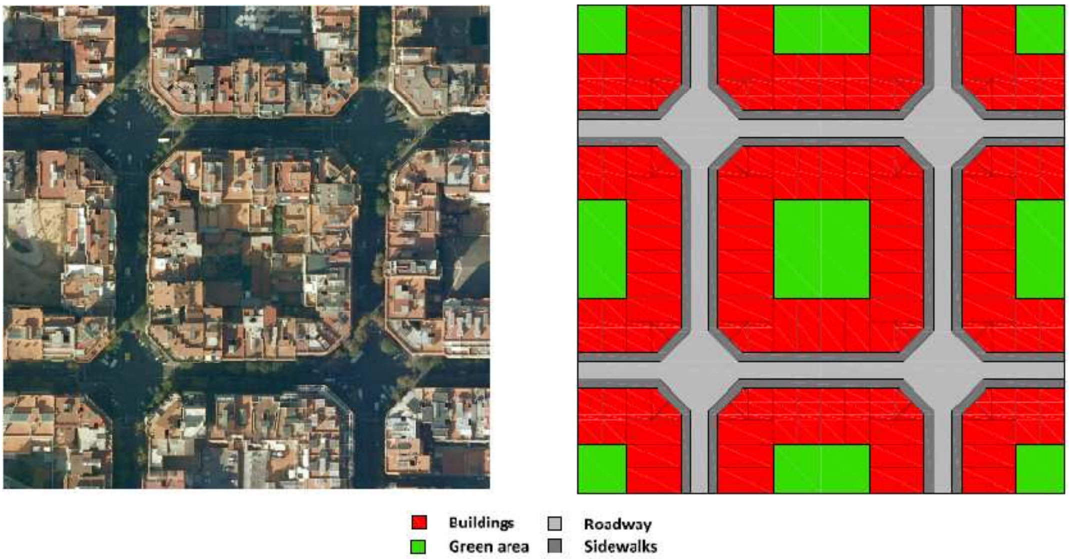


FIGURE 3. Plan view of Barcelona and the elemental unit of the A2 model. Scale 1/4000. Land use distribution map. Source: Own creation.

5.2.3 *Vertical block open fabric*

The next model is the named *vertical block open fabric* representative of high dense urban areas with detached blocks among green areas, and specially in that case malls. The inspiring case has been the Taikoo Shing residential complex located in Hong Kong Island (China). Furthermore, as we may appreciate in the following pictures, there is a highway with a junction which provides access to the local streets.

The buildings considered here have thirty floors and a ground floor for commercial purposes in between towers. The blue area is four floors equipment with three basements while the basement of the residential buildings has 3 or 4 floors.

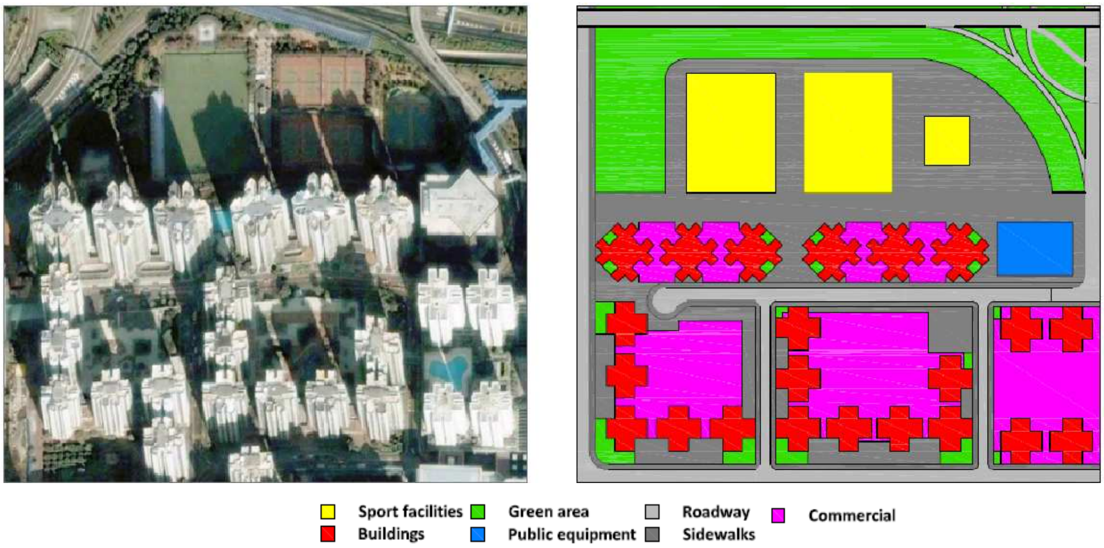


FIGURE 4. Plan view of Hong Kong and the elemental unit of the B1 model. Scale 1/5000. Land use distribution map. Source: Own creation.

5.2.4 *Horizontal block open fabric*

The *horizontal block open fabric* it is characterized by great green open spaces and dwellings in between giving a sensation of greener area inside cities. Horizontal block means a building where the horizontal dimension is larger than the vertical one. Another resounding feature of that model consists of the vast green areas between buildings and the peripheral main road that provide access to the local roads and parking. That model has been inspired from a metropolitan district in Moscow (Russia) which its satellite view is shown in the next photo, while on the right side appears the created model with its land use distribution.

The building heights range from 6, 12 and 16 floors. There are no basements in that case, where the vehicles are supposed to park in the outside parking.

FIGURE 5. Plan view of Moscow and the elemental unit of the B2 model. Scale 1/8000. Land use distribution map. Source: Own creation.

5.2.5 *Reticular detached houses*

The *reticular detached houses* model belongs to low-density urban structures. The street layout follows a grid pattern with streets and avenues. The urban fabric is closed with private gardens and wooden fences tracking the lots. Below, on the left side it is shown the satellite view of the inspiring real case located in Suburban Chicago (USA). And on the right side there is the model generated to represent the reticular detached houses model.

The building typology is a single family house with two floors in average. They have private paved access to a garage located in the back side of the lot.

FIGURE 6. Plan view of Chicago and the elemental unit of the C1 model. Scale 1/2000. Land use distribution map. Source: Own creation.

5.2.6 *Fractal detached houses*

The last model is the *fractal detached houses* belonging to low-density urban forms as well with a particular feature of fractal street layout. The fractal distribution tries to optimize the street length within a given area saving in turn public infrastructure.

The next pattern presented below on the left side corresponds in the real case of the Orange district in Los Angeles of California (USA). Bearing that pattern in mind on the right side is shown the equivalent ideal model created.

Regarding the building features, those are single family houses with an average of 2 floors and private paved access vehicles.

FIGURE 7. Plan view of Los Angeles and the elemental unit of the C2 model. Scale 1/6000. Land use distribution map. Source: Own creation.

6 DESIGN AND SIZING OF THE URBAN MODELS

6.1 Definition of the study areas

In order to compare similar models with resembling features there has been an analysis of the study area. It has been considered to expand the models until reach a homogeneous size. In that form we may design and size the service networks equally in terms of not include only the basic system but also to consider the high-transport facilities of each network. Therefore, the elemental unit of each model has been replicated as many times as is required to get a homogeneous project area. Finally, the mean total project area has been 27.57 hectares accepting a typical deviation of 5% as it is shown in the following table linked with a bar chart.

	Code	**Pattern area (Ha)**	**Number of replications**	**Total project area (Ha)**
American closed fabric	A1	7.343	4	29.372
European closed fabric	A2	7.076	4	28.302
Vertical block open fabric	B1	12.601	2	25.202
Horizontal block open fabric	B2	28.036	1	28.036
Rectilinear detached houses	C1	4.543	6	27.259
Fractal detached houses	C2	27.232	1	27.232
Mean				27.567
Standard deviation				14.014
Typical deviation				5.083

TABLE 12. Pattern area and total study area (Ha),

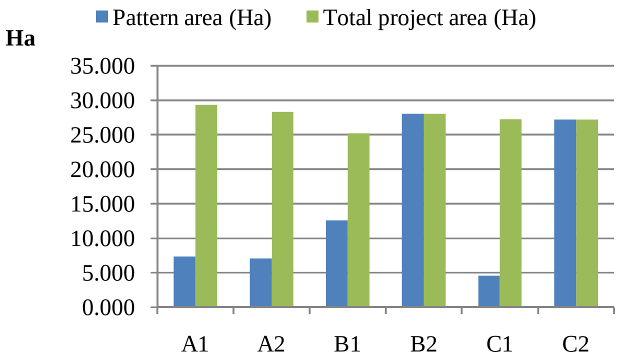


FIGURE 8. Total study area chart (Ha).

As we may appreciate from the bar chart above the minimum common multiplier to obtain the total project area have been both the *horizontal block open fabric* and the *fractal detached houses*. The two types of closed fabric have been multiplied four times, while the *vertical block open fabric* and *rectilinear detached houses* have been expanded two and six time respectively.

6.2 Infrastructure of urban services

The services and networks studied in this paper are drainage system, drinking water, sewage system, lighting and tree alignment. These networks has been specifically designed and sized to provide the levels of service demanded in the current legislation in order to evacuate rainwater, sewage, provide potable water and lighting to extend daily activities during the night. These networks are detailed in the sections below.

6.2.1 *Drainage system*

The drainage system is the network destined to evacuate rainwater in both the public and private space in the whole project area for a return period of ten years. Normally the course of this network passes through underneath the roadway or sidewalks due to its dimensions and to let space enough for further maintenance works. Furthermore, all the trenches have been designed with more the 1.4 meters depth as the legislation on the field stresses for security reasons.

The drainage system has been designed that flows thanks to gravity with a maximum flow of up to 80% of its capacity as a security factor. Moreover, in all models it has been adopted the hypothesis that there is a constant slope of 1% on both sides and with a sole evacuation point as it is shown in the sketch below.

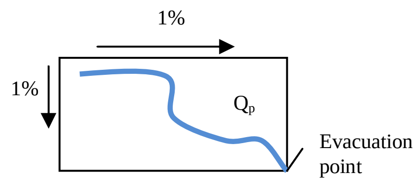


FIGURE 9. Draining course and flow direction. Source: Own creation.

6.2.1.1 Calculation of gutter separation

The gutters are the items in the roadway entrusted to collect rainwater and drive it to a main drainage tube. They are located just next to the sidewalk kerb in the roadway border. Normally, there is a roadway cross slope of 2% and 1.5% on sidewalks that drive rainwater (by means of gravity) towards the gutters. Manufactures provide charts of each gutter model with its capacity. The gutter considered in this study has a standard capacity of 18 l/s when the slopes are 0.5% and 8 l/s with slopes of 4%.

The calculations to find the gutter separation start from setting out the problem by the help of the following sketch:

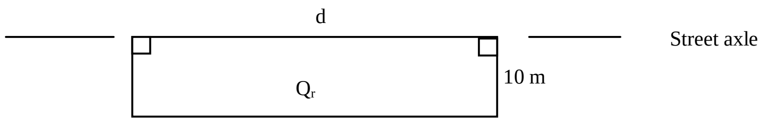


FIGURE 10. Study area for gutter separation calculation. Source: Own creation.

Where Q_r is the rainwater flow, d is the distance between two gutters and 10 meters is a given street width. The rainwater flow is given by the following formula:

$$Q_r = C * I * A = 400 \, {}^{l/s}\!/_{Ha}$$

The following equation is given by the manufacturer and represents the gutter capacity in function of the surrounding slopes.

$$Q_e(i\%) = -2{,}86 \cdot i + 19{,}44$$

Taking 1% of slope in average we get:

$$Q_e(1\%) = 16{,}58 \, l/s$$

Making equal the two flows and isolating our unknown (d) we get:

$$Q_r = Q_{r/Ha} \cdot A = \left(\frac{400}{10000}\right) \cdot 10 \cdot d = 0{,}4 \cdot d$$

$$Q_p = Q_e(1\%) \rightarrow 16{,}58 l/s = 0{,}4 \cdot d \rightarrow d = 41{,}45 m \approx 40 m$$

6.2.1.2 Reference flow calculation

To calculate the diameters of the drainage system it has been designed according the *Instruction 5.2-IC "Superficial Drainage" (14-5-90).*

6.2.1.2.1 General Approach

The estimation method of the volume flows associated to different return periods depends on the size and nature of the contributing basin.

For small basins, hydrometeorological methods based on the application of a mean intensity of precipitation on the basin surface, through an estimation of runoff, are appropriated. This is equivalent to admit that the only component of the precipitation which takes part in the maxim volume flow generation runoffs superficially.

In larger basins these methods loss accuracy, so the estimation of the flows is less correct. On the other hand, in these basins it is common to have direct information about either flood levels or flows. The boundary between large and small basins corresponds approximately to a concentration time equal to six hours.

The nature basin influences to hydrometeorological methods, depending on if the diffused flow time of travel over the land is significant (road platform and sides in which it spills) or not (defined bed). Especially in urban zones, it represents a singularity the presence of drains which drain in a piping and which absorbs an important part of the runoff.

They also represent especial cases the presence of lakes, reservoirs and flood zones which either laminate or alter the course of the runoff. It will be possible to take into account, the contribution from the thaw provided that it is not larger than 10%, apart from exceptional cases.

The result of the hydrometereological methods must be contrasted, as far as possible, with the available direct information about levels and flood flows.

6.2.1.2.2 Design Formulae (hydrometereological method)

The reference volume flow Q at the point where a basin drains will be obtained through the formulae:

$$Q = C \cdot A \cdot I / K$$

Where:

- C: Either runoff average coefficient of the basin or drained surface.
- A: Area, unless that it has either contributions or important losses such as reemerged fresh waters and drains, in that case the design flow must be justified.
- I: Average intensity of precipitation corresponding to the considered return period and an interval equal to the concentration time.

K: Coefficient depending on the units in which Q and A are expressed and include and increase of 20% over Q in order to take into account the precipitation peaks. Its value is collected in the following table.

Q	A		
	Km^2	Ha	m^2
m^3/s	3	300	3.000.000
l/s	0,003	0,3	3

FIGURE 11. K values.

6.2.1.2.3 Average Intensity of precipitation

The average intensity of precipitation I_t (mm/h) to use for the estimation of reference flows by hydrometeorological methods can be obtained through the following formulae:

$$\left({}^{I_t}/_{I_d} \right) = \left({}^{I_1}/_{I_d} \right)^{\frac{28^{0.1} - t^{0.1}}{28^{0.1} - 1}}$$

Where:

Id (mm/h): Daily average intensity of precipitation, corresponding to the return period considered. It is equal to ${}^{P_d}/_{24}$.

Pd (mm): Total daily precipitation corresponding to named return period. In particular, for this study it has been taken a general value of 100 mm for a return period of 10 years.

I1 (mm/h): Horary precipitation intensity corresponding to this return period. Again, for this study, the ratio ${}^{I_t}/_{I_d}$ has been generalized in a value of 11 for all the patterns.

t (h): Length of the interval that I refers, which will be taken equal to the concentration time (see next section).

6.2.1.2.4 Concentration time

For the case of normal basins in which the channelized flow travel time through a net of defined beds, the concentration time T(h) related with the average precipitation intensity can be deduced from the formulae:

$$T = 0.3 \left[\left(\frac{L}{J^{1/4}} \right)^{0.76} \right]$$

Where:

L (km): Length of the main bed.

J (m/m): Average slope.

If the travel time for diffused flow over the land was relatively significant, as it is for the road platform case and the sides in which it spills, the above formulae could not be applied.

If the travel of the water flow on the surface was lower than 30m, it could be considered that the concentration time is five minutes. This value can be increased from five up to ten minutes when the travel distance of the water through the platform is increased from 30 until 150 m.

6.2.1.2.5 Runoff

The coefficient C of runoff defines the proportion of the component superficial of the precipitation of intensity I and depends on the ratio between the diary precipitation P_d corresponding to the return period and the threshold of runoff from which it is initiated.

For the current study the C value has been considered as show the following table.

Surface	C
Roadway	0.95
Sidewalk	0.95
Building	0.85
Green area	0.35

FIGURE 12. Runoff coefficient values.

The heterogenic basin must be divided in partial areas whose runoff coefficient will be calculated separately, replacing after the term C·A of the formula above for the summation of $(C_i \cdot A_i)$ being “i” each type of land use.

6.2.1.2.6 Drainage basins

The following figure shows the drainage basins considered for the drainage system calculation being the blue lines the basin boundaries.

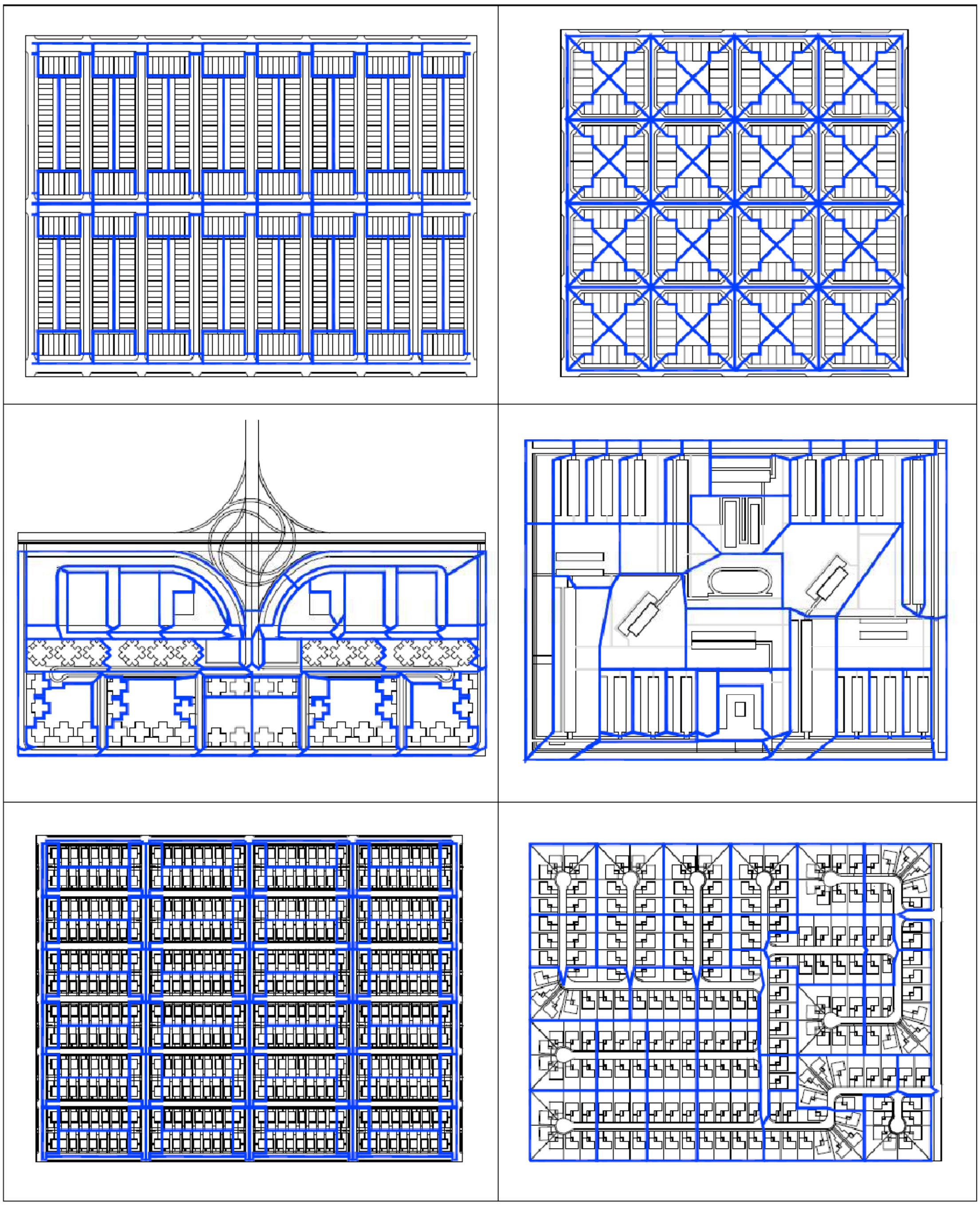


FIGURE 13. Drainage basins.

6.2.1.3 Drainage system layout

In this section it is shown the result of the calculation of diameter pipes. Additionally to the computations, there has been a deep study of the system layout in terms of the proper course according street distances and urban morphology. The picture below represents the final design of the drainage system. The thicknesses and colors of the lines correspond to the different diameters of the pipes. For more detail see the annex of maps.

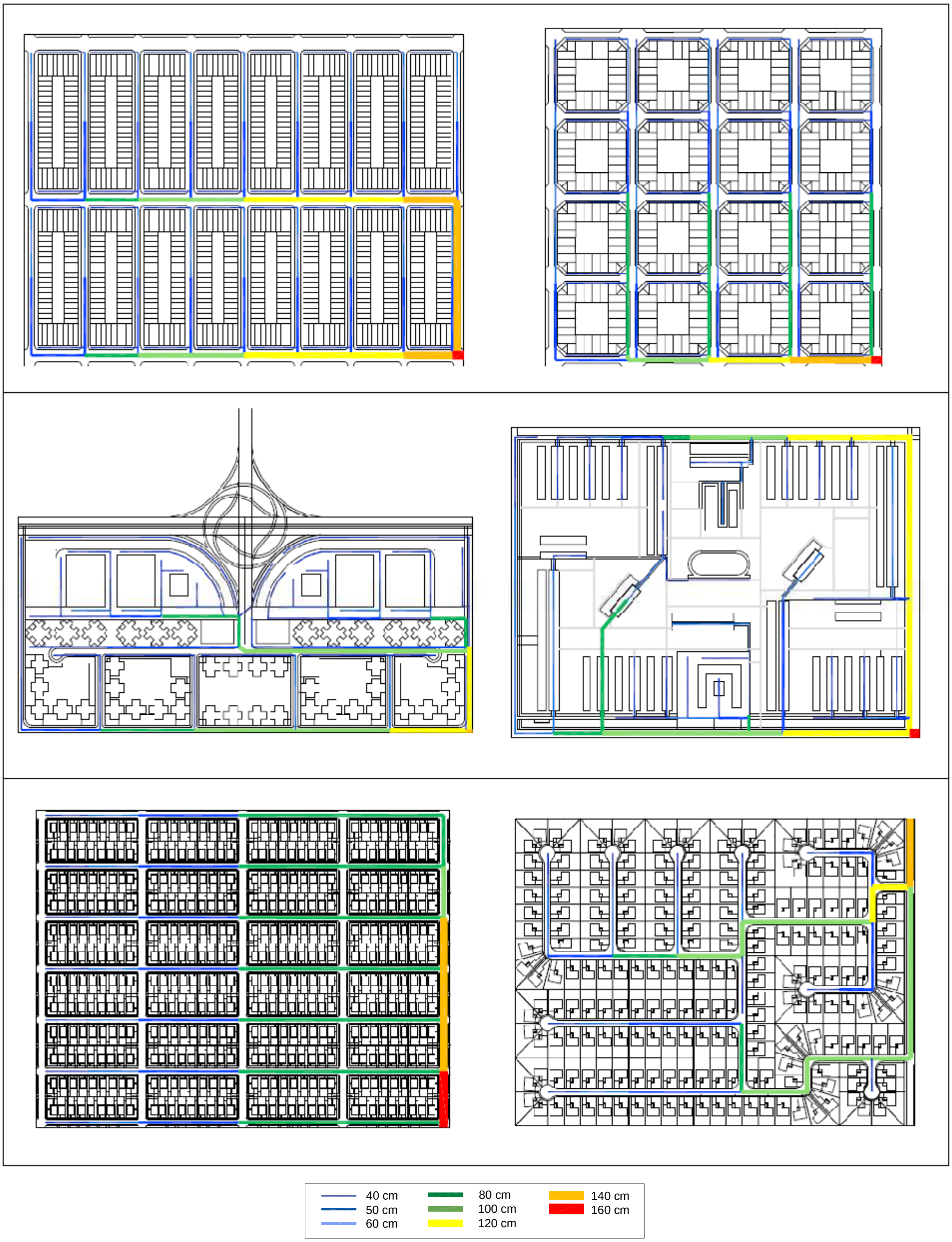


FIGURE 14. Final drainage system network design.

6.2.2 *Drinking water*

The drinking water system has been designed according to provide potable water equally in all the dwellings adopting a peripheral ring layout. It is important to bear in mind that this network functions by pressure normally by a water tower located in a higher position than the buildings.

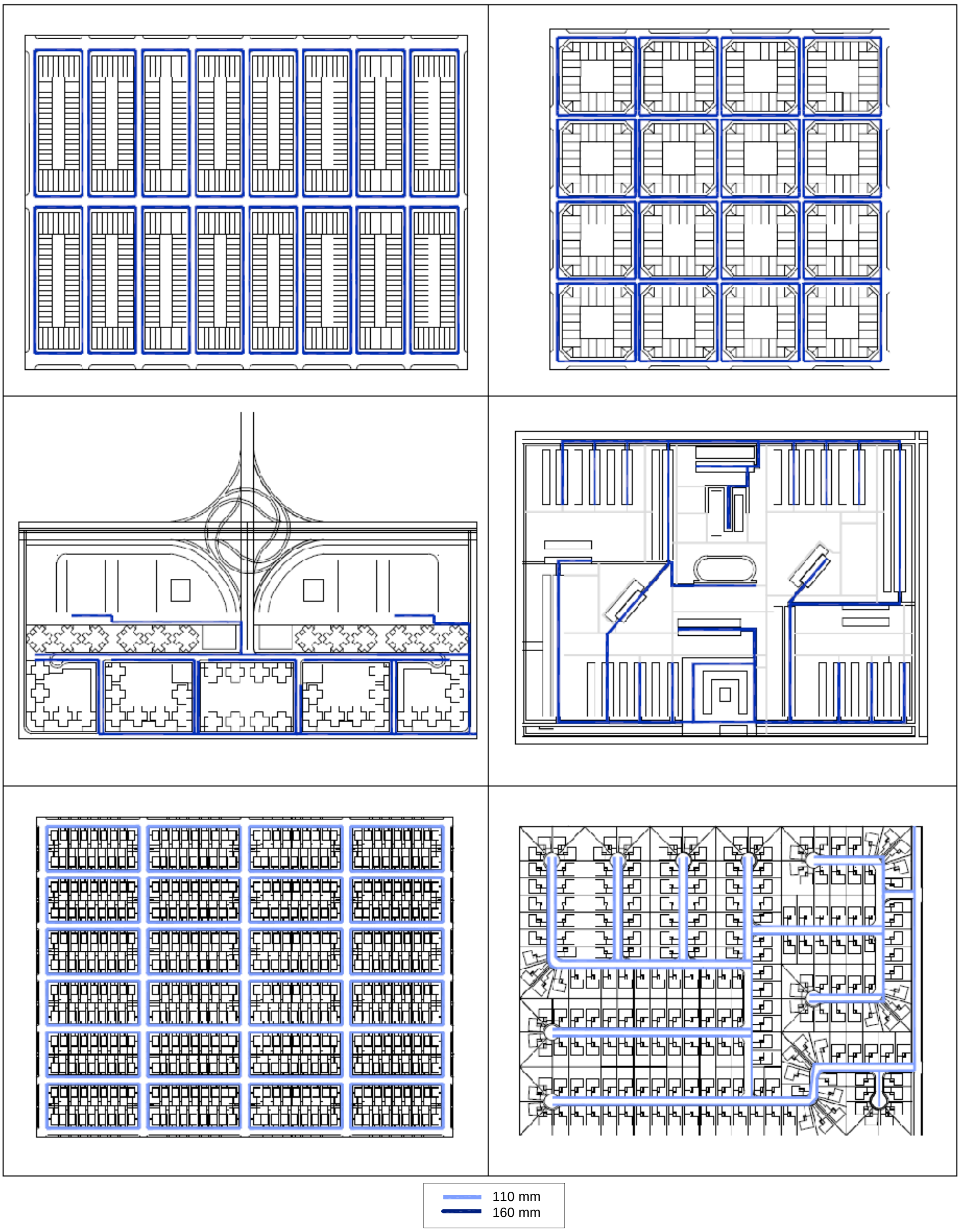


FIGURE 15. Final design of the drinking water system.

6.2.3 *Sewage system*

The sewage system is the service network that collects the liquid waste generated in households which is drained in a separate network than rainwater.

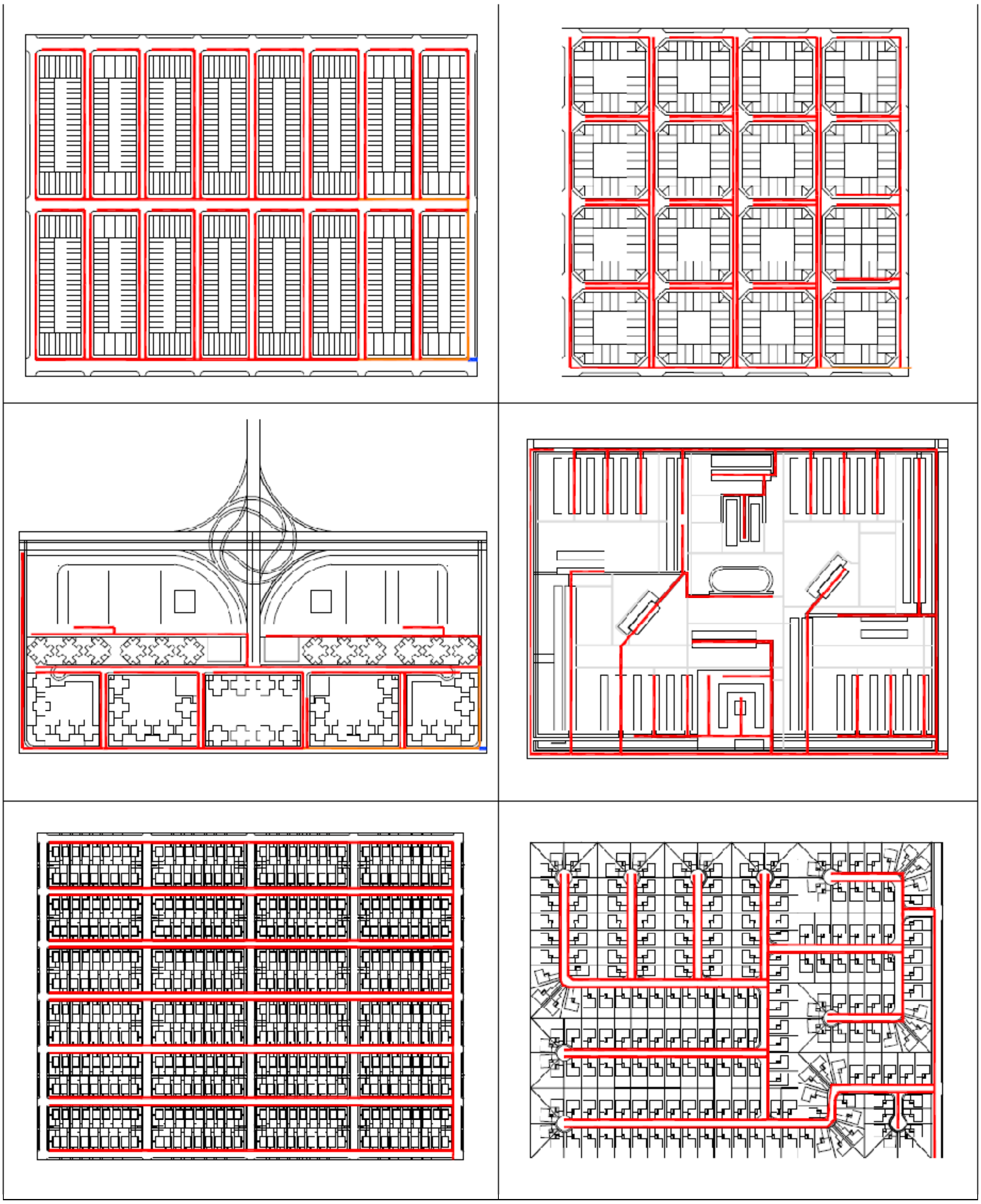
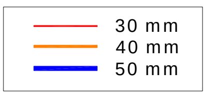


FIGURE 16. Final design of the sewage system.



The problematic risen of putting together the two flows is on the one hand, that the rainwater becomes polluted due to the mixing with waste water, and on the other hand, the flow that reach the Waste Treatments Plants WTP becomes larger and in turn more expensive and bigger WTP.

The course of this network have been arranged normally with the same route than drainage system taking into consideration that this networks function thanks to gravity as well.

6.2.4 *Tree alignment and lighting*

The tree alignment and lighting has been carefully designed in order to arrange the public space for daily and night life and to provide the levels of night light demanded in each kind of way in function of their functional purposes. There has been a reduction up to 40% of the lighting levels due to the vegetation denseness result of either a bad design or bad pruned. A bad design of the tree alignment may cause insecurity for drivers and pedestrian user of these facilities. Another fact that makes crucial a proper lighting design is the squander of electricity consumption and the rise on the municipality electric bill supposing up to 60% of the municipal investment on electricity.

In this chapter have been a reflection on the problematic of tree alignment-lighting with the aim of achieves an integrated design satisfying the requirements of security, sustainability and esthetic of the arrangement of our streets.The criteria followed when designing the public lighting has been the current legislation, relation roadway-sidewalk, lighting degree, regularity, uniformity, and interference with others aerials networks. Regarding the street trees the criteria that we have tried to fulfill has been the current legislation, arrangement of the section, continuity, connectivity, readability, urban landscape, parking, and street crossings.

Finally the integrated design strives for a proper composition and pace, relative heights, light cones and interferences, relative arrangement according to lamp types, proper volumetric reserve for tree growth, and prune aspects.

Model	Road category	Lamp-posts distribution	Lamp-post height (m)	Lamp-post separation (m)	Bulb power (W)	COLOR
A1	Avenue	bilateral	10	27	250	
	street	staggered	8	20	150	
A2	street	staggered	8	20	150	
B1	Avenue	bilateral	10	27	250	
	collector	staggered	8	20	150	
	Local	staggered	6	15	100	
	Allée	bilateral	6	20	100	
	Promenade1	staggered	6	15	100	
	Promenade2	unilateral	8	20	150	
	Pedestrian	unilateral	6	16	100	
B2	Avenue	bilateral	10	27	250	
	collector	unilateral	6	15	100	
	Parking 1	bilateral	8	20	150	
	Access	unilateral	6	15	100	
	Parking2	staggered	8	20	150	
	Path	unilateral	3	10	70	
C1	Avenue	staggered	10	25	250	
	street	staggered	8	20	150	
C2	Avenue	bilateral	10	27	250	
	Local	unilateral	10	27	250	

TABLE 13. Public lighting features,

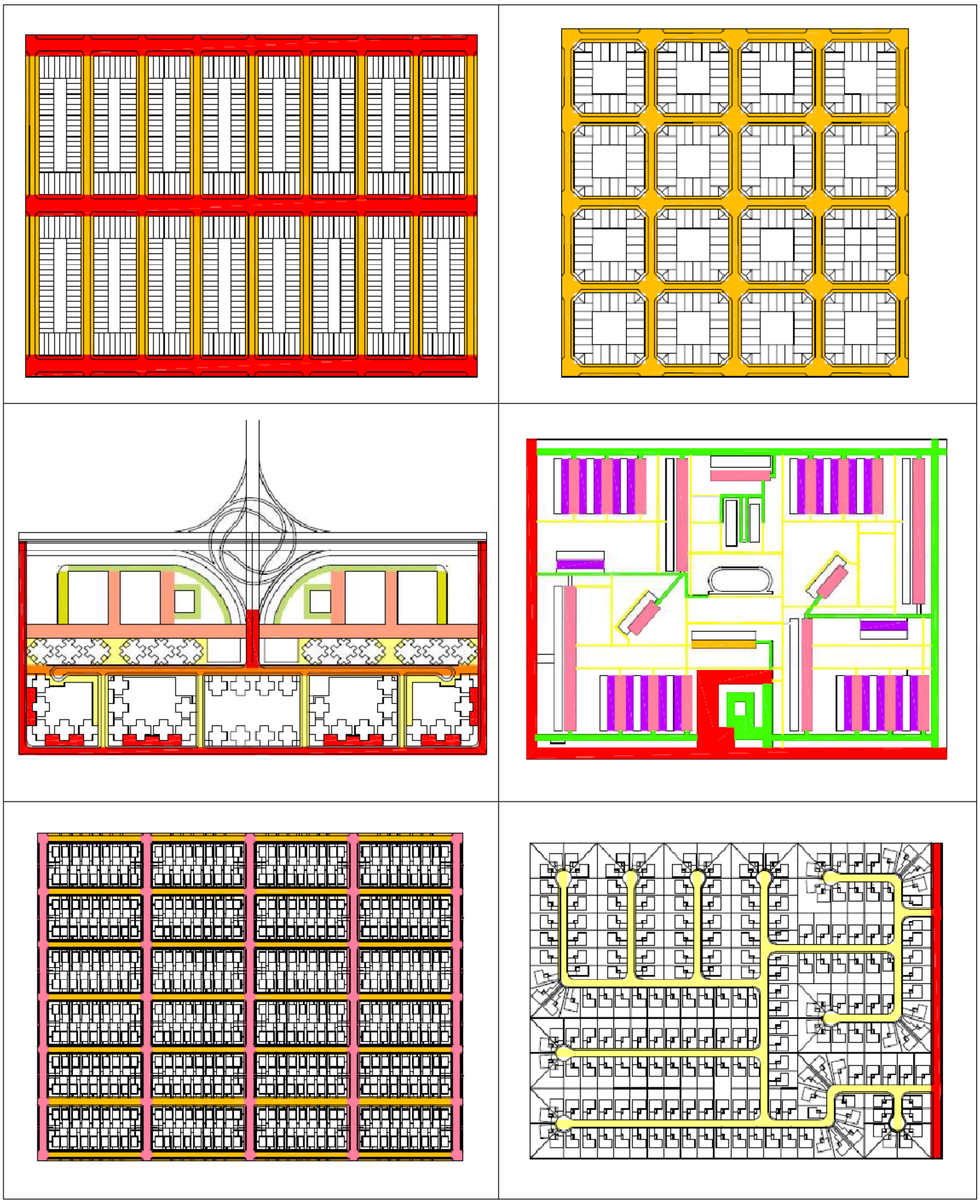


FIGURE 17. Final public lighting design

The following table describes the street trees considered for the present study.

Model	Road category	Tree specie	Average distance (m)
A1	Avenue	-	-
	street	Pyrus communis	20.3
A2	street	Platanus Hispanica	20.13
B1	Avenue	-	-
	collector	-	-
	Local	Koelreuteria paniculata	15
	Allée	Koelreuteria paniculata	10
	Promenade1	-	-
	Promenade2	Koelreuteria paniculata	10
	Pedestrian	Koelreuteria paniculata	10
B2	Avenue	Alnus glutinosa	20.2
	collector	Alnus glutinosa	19.5
	Parking 1	Alnus glutinosa	22.5
	Access	Alnus glutinosa	20.2
	Parking2	Alnus glutinosa	21
	Path	Alnus glutinosa	8.5
C1	Avenue	Pyrus communis	17.03
	street	Pyrus communis	8.8
C2	Avenue	Pyrus communis	6.21
	Local	-	-

TABLE 14. Street trees final design.

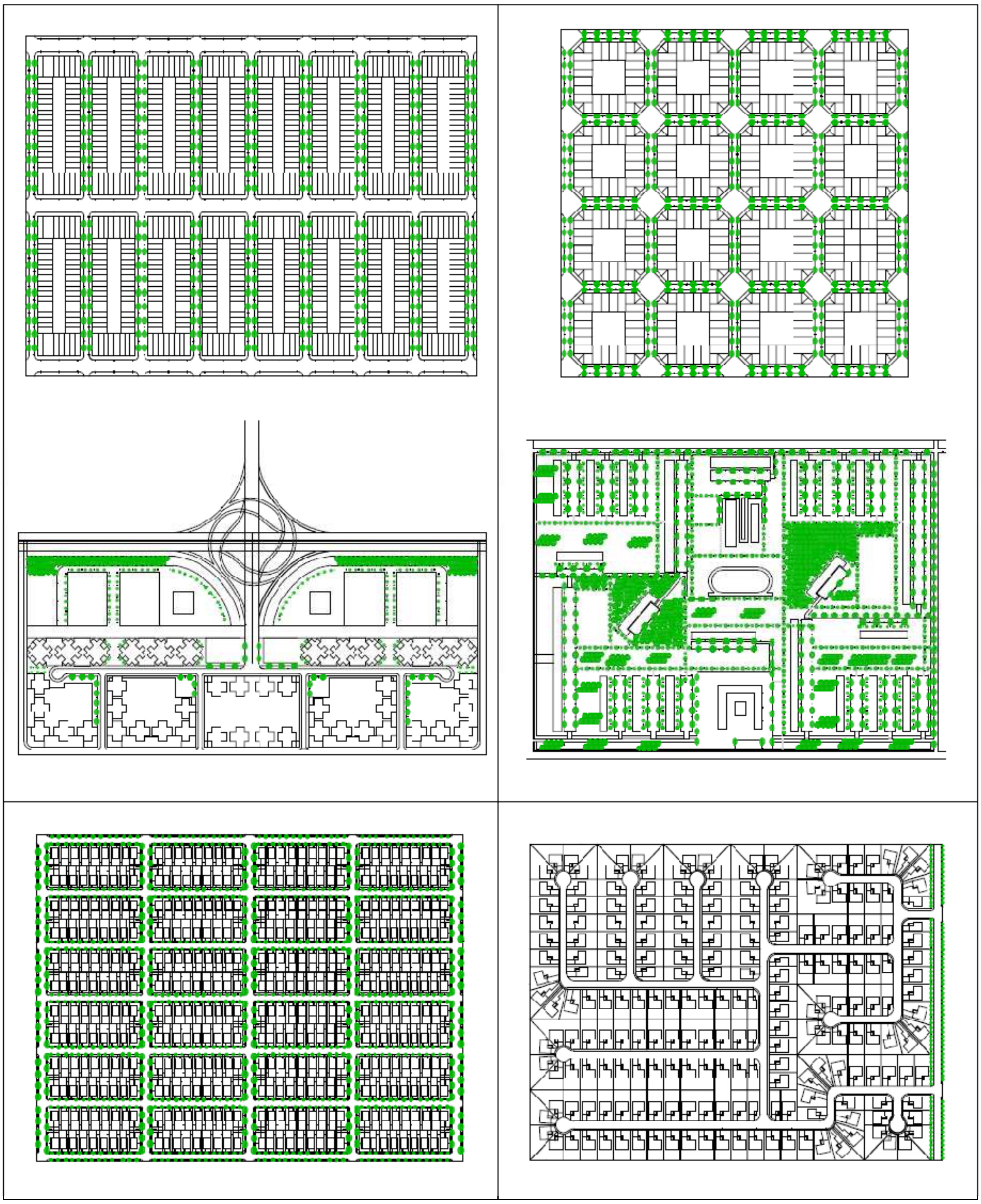
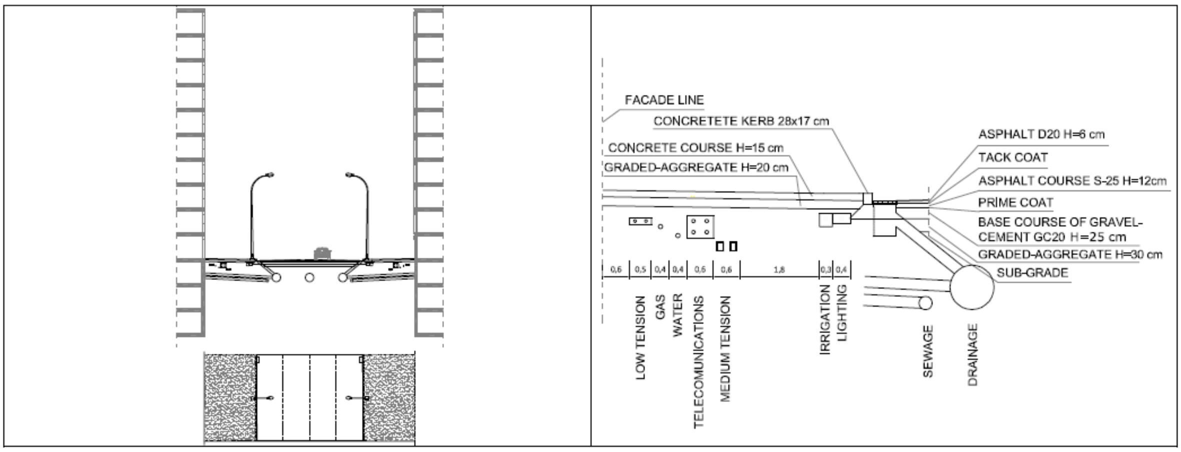


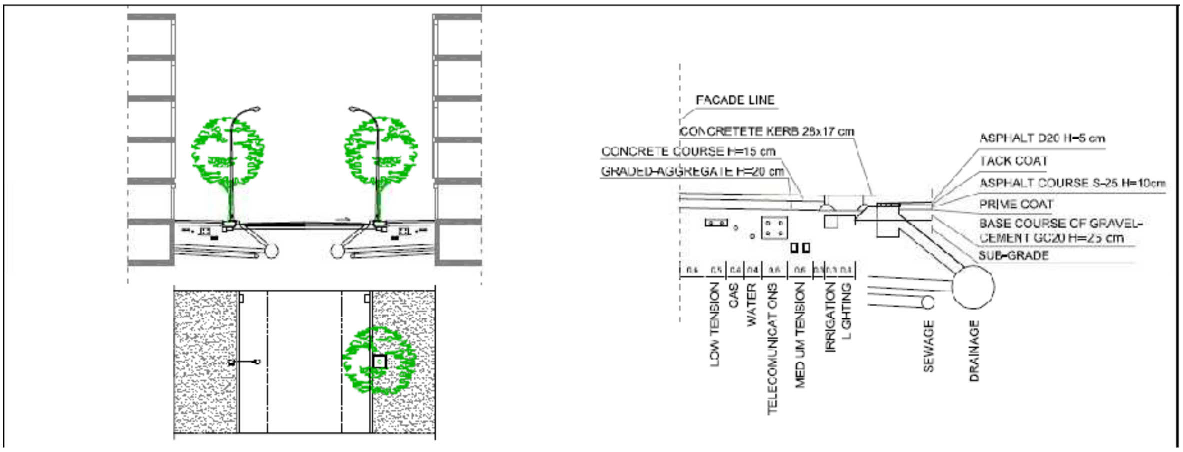
FIGURE 18. Street trees final design.

6.3 Street sections

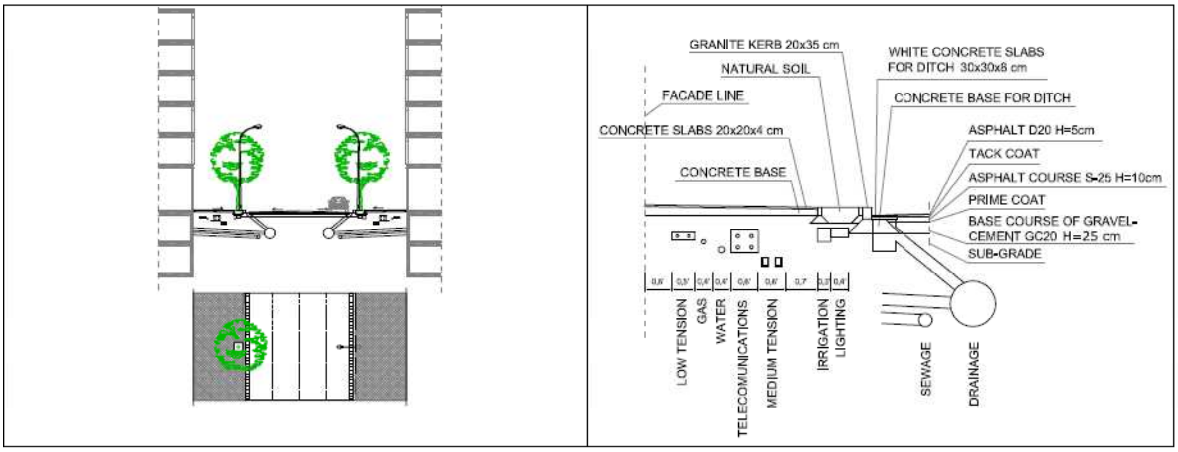
The current chapter defines the street section taken into consideration for the road infrastructure and public service networks. Regarding the road infrastructure there are different thicknesses of its composing layers as it is shown in the next drawings.



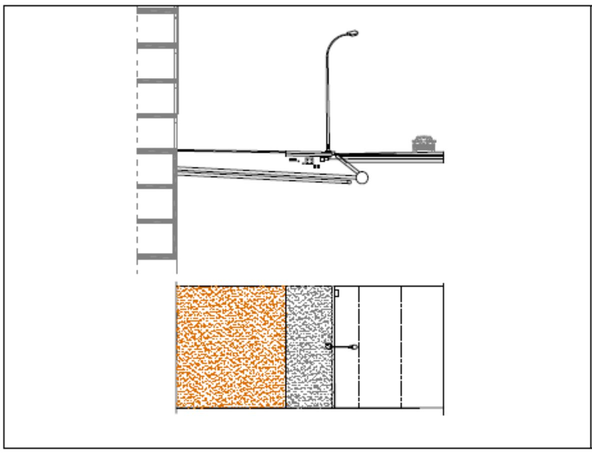
Pattern		A1	**Roadway structure**	**Asphalt D-20 (cm)**	6
Street type		avenue		**Asphalt S-25 (cm)**	12
Lighting	**Distribution**	bilateral		**Gravel-cement GC20 (cm)**	25
	Height (m)	10		**Graded-aggregate (cm)**	30
	Distance (m)	27	**Sidewalk structure**	**Concrete (cm)**	15
	Power (W)	250		**Graded-aggregate (cm)**	20
	Section	troncoconic		**kerb material**	concrete
	Lamp	HPSSL	**Drainage tube material**		concrete
Tree	**Type**	-	**Sewage tube**	**D = 300 mm**	PVC
	Average distance (m)	-		**D = 400 mm**	concrete
				D = 500 mm	concrete
			Drinking water tube material		polyethylene

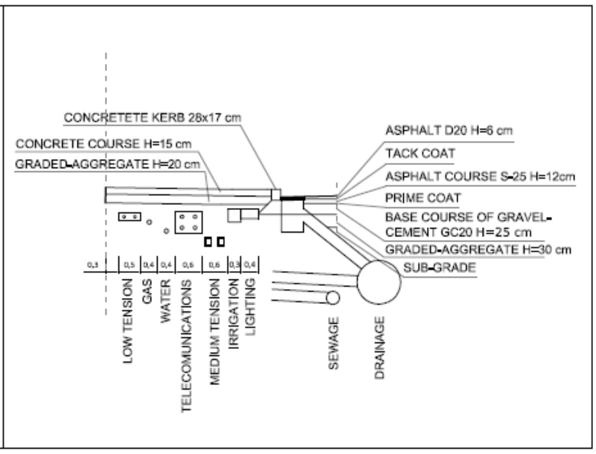


Pattern		A1	**Roadway structure**	**Asphalt D-20 (cm)**	5
Street type		street		**Asphalt S-25 (cm)**	10
Lighting	**Distribution**	staggered		**Gravel-cement GC20 (cm)**	25
	Height (m)	8	**Sidewalk structure**	**Concrete (cm)**	15
	Distance (m)	20		**Graded-aggregate (cm)**	20
	Power (W)	150		**Kerb type**	concrete
	Section	troncoconic	**Drainage tube material**		concrete
	Lamp	HPSSL	**Sewage tube**	**D = 300 mm**	PVC
Tree	**Type**	Pyrus communis		**D = 400 mm**	concrete
	Average distance (m)	20.3	**Drinking water tube material**		polyethylene

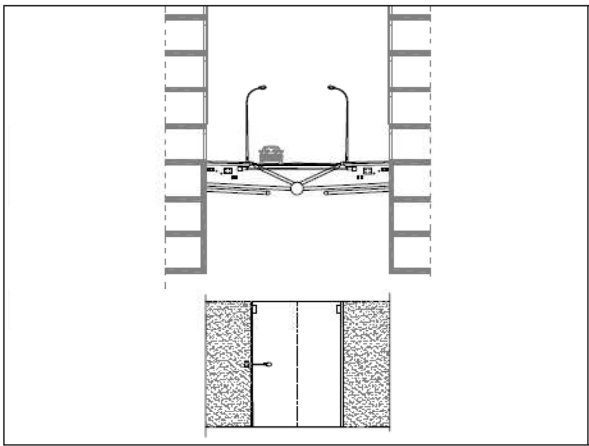


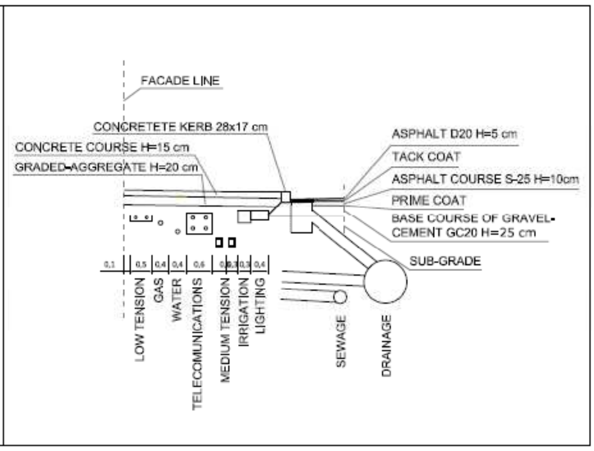
Pattern		A2	**Roadway structure**	**Asphalt D-20**	5
Street type		street		**Asphalt S-25**	10
Lighting	**Distribution**	staggered		**Gravel-cement GC20**	25
	Height (m)	8		**White concrete slabs for ditch (cm)**	30x30x8
	Distance (m)	20			
	Power (W)	150	**Sidewalk structure**	**Concrete slabs (cm)**	20x20x4
	Section	troncoconic		**Concrete base (cm)**	15
	Lamp	HPSSL		**Kerb type**	granite
Tree	**Type**	Platanus Hispanica	**Drainage tube material**		concrete
	Average distance (m)	20.13	**Sewage tube**	**D = 300 mm**	PVC
				D = 400 mm	concrete
			Drinking water tube material		polyethylene



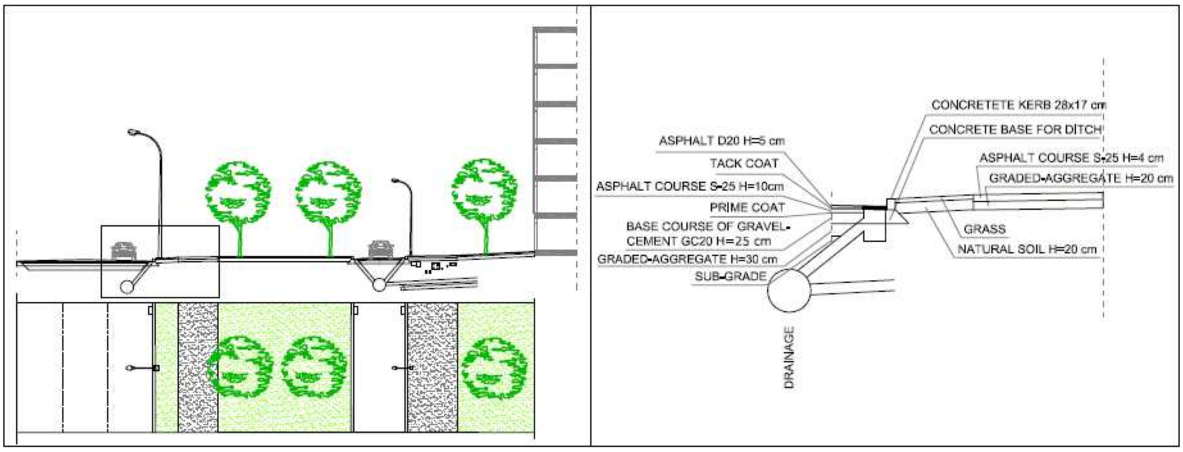


Pattern		B1	**Roadway structure**	**Asphalt D-20 (cm)**	6
Street type		avenue		**Asphalt S-25 (cm)**	12
Lighting	**Distribution**	bilateral		**Gravel-cement GC20 (cm)**	25
	Height (m)	10		**Graded-aggregate (cm)**	30
	Distance (m)	27	**Sidewalk structure**	**Concrete (cm)**	15
	Power (W)	250		**Graded-aggregate (cm)**	20
	Section	troncoconic		**kerb material**	concrete
	Lamp	HPSSL	**Drainage tube material**		concrete
Tree	**Type**	-	**Sewage tube**	**D = 300 mm**	PVC
	Average distance (m)	-		**D = 400 mm**	concrete
				D = 500 mm	concrete
			Drinking water tube material		polyethylene

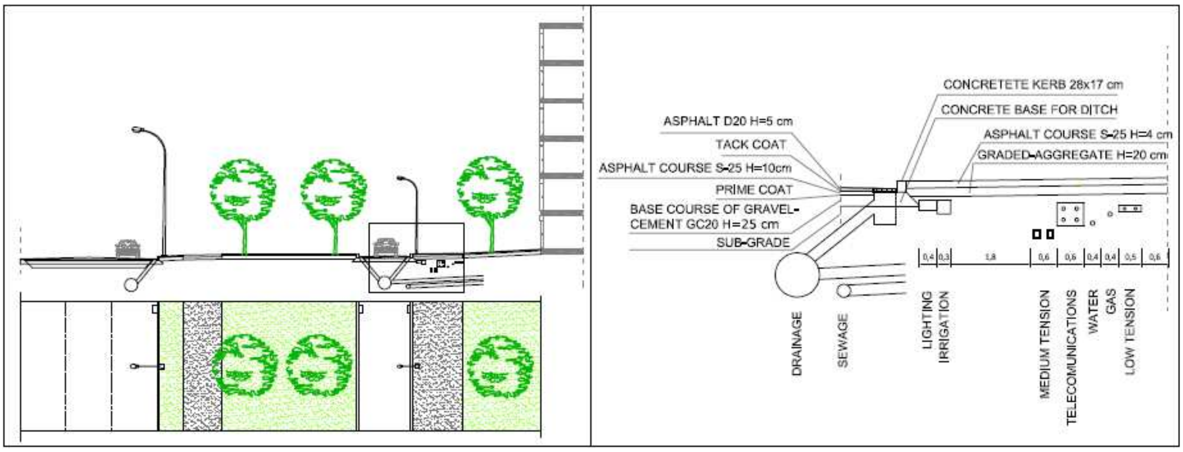




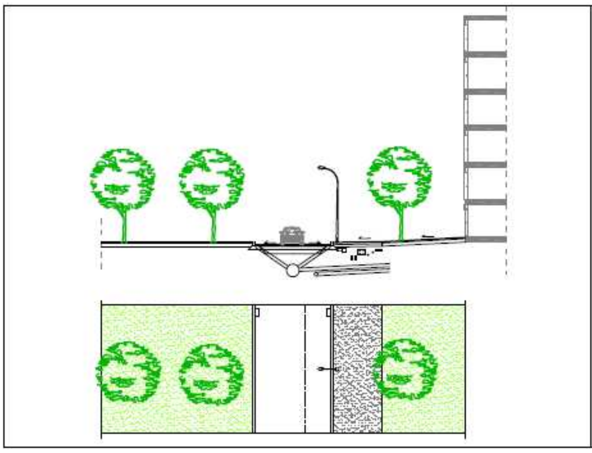
Pattern		B1	**Roadway structure**	**Asphalt D-20 (cm)**	5
Street type		local street		**Asphalt S-25 (cm)**	10
Lighting	**Distribution**	staggered		**Gravel-cement GC20 (cm)**	25
	Height (m)	6	**Sidewalk structure**	**Concrete (cm)**	15
	Distance (m)	15		**Graded-aggregate (cm)**	20
	Power (W)	100		**Kerb type**	concrete
	Section	troncoconic	**Drainage tube material**		concrete
	Lamp	HPSSL	**Sewage tube**	**D = 300 mm**	PVC
Tree	**Type**	elreuteria panicula		**D = 400 mm**	concrete
	Average distance (m)	pedestrian entrance	**Drinking water tube material**		polyethylene

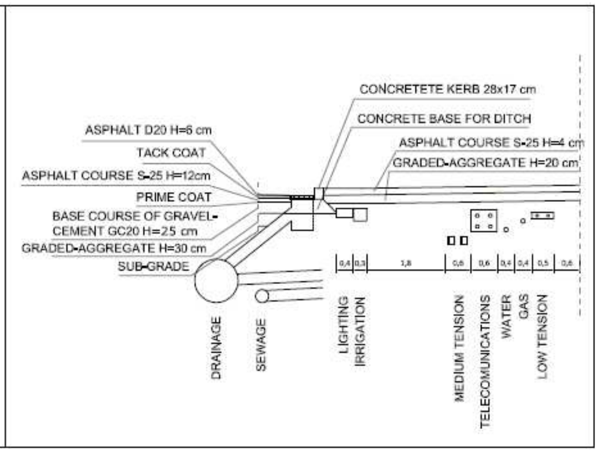


Pattern		B2	**Roadway structure**	**Asphalt D-20 (cm)**	6
Street type		avenue		**Asphalt S-25 (cm)**	12
Lighting	**Distribution**	bilateral		**Gravel-cement GC20 (cm)**	25
	Height (m)	10		**Graded-aggregate (cm)**	30
	Distance (m)	27	**Sidewalk structure**	**Asphalt S-25 (cm)**	4
	Power (W)	250		**Graded-aggregate (cm)**	20
	Section	troncoconic		**kerb material**	concrete
	Lamp	HPSSL	**Drainage tube material**		concrete
Tree	**Type**	Alnus glutinosa	**Sewage tube**	**D = 300 mm**	PVC
	Average distance (m)	20.2		**D = 400 mm**	concrete
				D = 500 mm	concrete
			Drinking water tube material		polyethylene

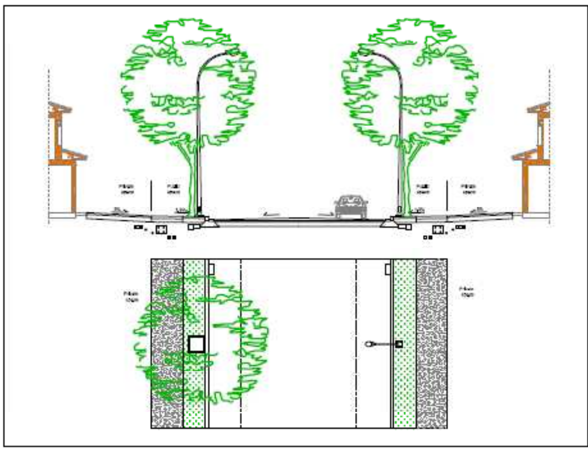


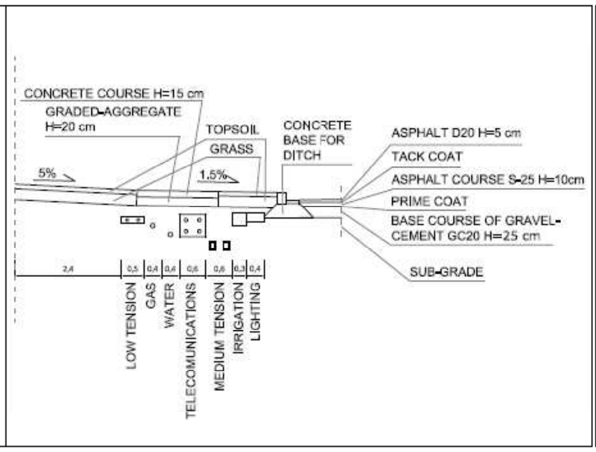
Pattern		B2	**Roadway structure**	**Asphalt D-20 (cm)**	5
Street type		access		**Asphalt S-25 (cm)**	10
Lighting	**Distribution**	unilateral		**Gravel-cement GC20 (cm)**	25
	Height (m)	6	**Sidewalk structure**	**Asphalt S-25 (cm)**	4
	Distance (m)	15		**Graded-aggregate (cm)**	20
	Power (W)	100		**Kerb type**	concrete
	Section	troncoconic	**Drainage tube material**		concrete
	Lamp	HPSSL	**Sewage tube**	**D = 300 mm**	PVC
Tree	**Type**	Alnus glutinosa	**Drinking water tube material**		polyethylene
	Average distance (m)	20.2			



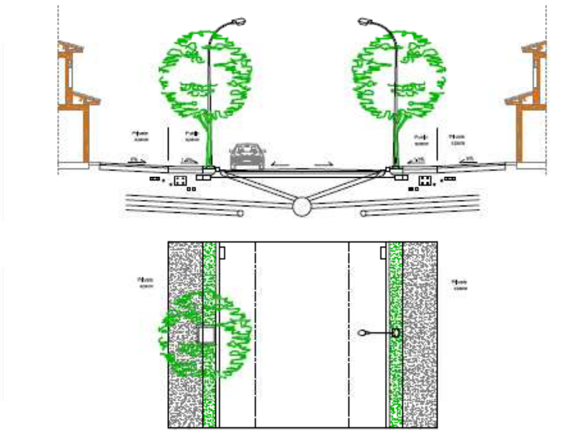


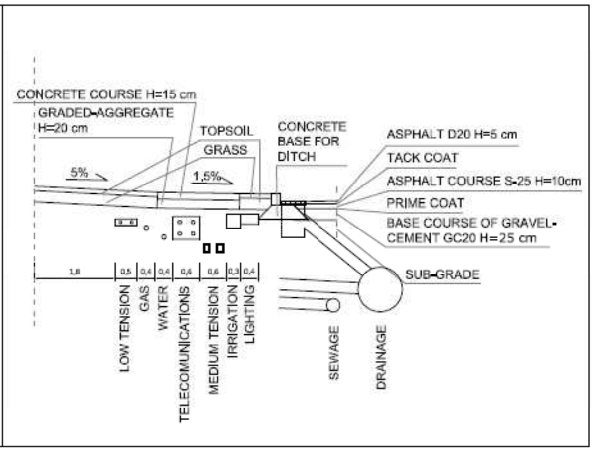
Pattern		B2	**Roadway structure**	**Asphalt D-20 (cm)**	6
Street type		collector		**Asphalt S-25 (cm)**	12
Lighting	**Distribution**	unilateral		**Gravel-cement GC20 (cm)**	25
	Height (m)	6		**Graded-aggregate (cm)**	30
	Distance (m)	15	**Sidewalk structure**	**Asphalt S-25 (cm)**	4
	Power (W)	100		**Graded-aggregate (cm)**	20
	Section	troncoconic		**kerb material**	concrete
	Lamp	HPSSL	**Drainage tube material**		concrete
Tree	**Type**	Alnus glutinosa	**Sewage tube**	**D = 300 mm**	PVC
	Average distance (m)	19.5	**Drinking water tube material**		polyethylene



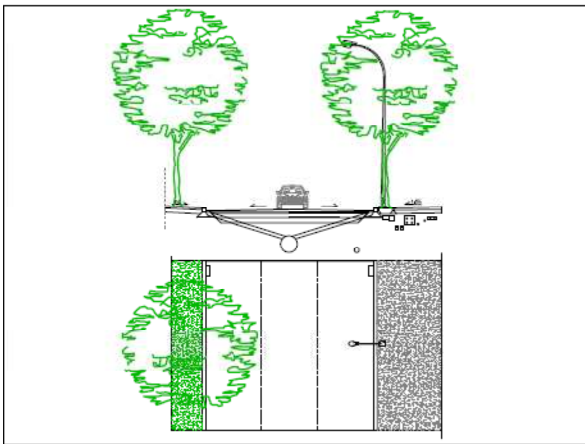


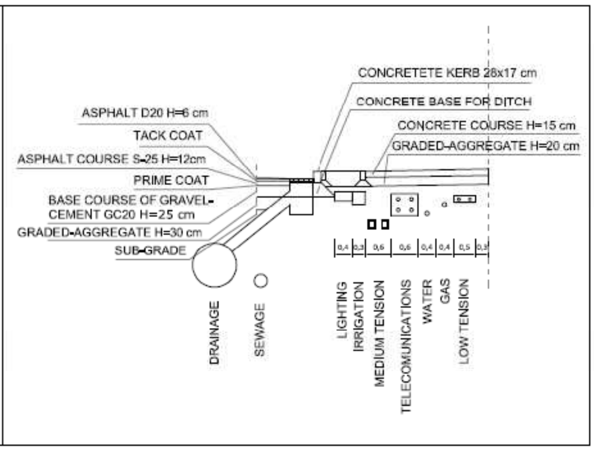
Pattern		C1	**Roadway structure**	**Asphalt D-20 (cm)**	5
Street type		avenue		**Asphalt S-25 (cm)**	10
Lighting	**Distribution**	staggered		**Gravel-cement GC20 (cm)**	25
	Height (m)	10	**Sidewalk structure**	**Concrete (cm)**	15
	Distance (m)	25		**Graded-aggregate (cm)**	20
	Power (W)	250		**Kerb type**	concrete
	Section	troncoconic	**Drinking water tube material**		polyethylene
	Lamp	HPSSL			
Tree	**Type**	Pyrus communis			
	Average distance (m)	17.03			



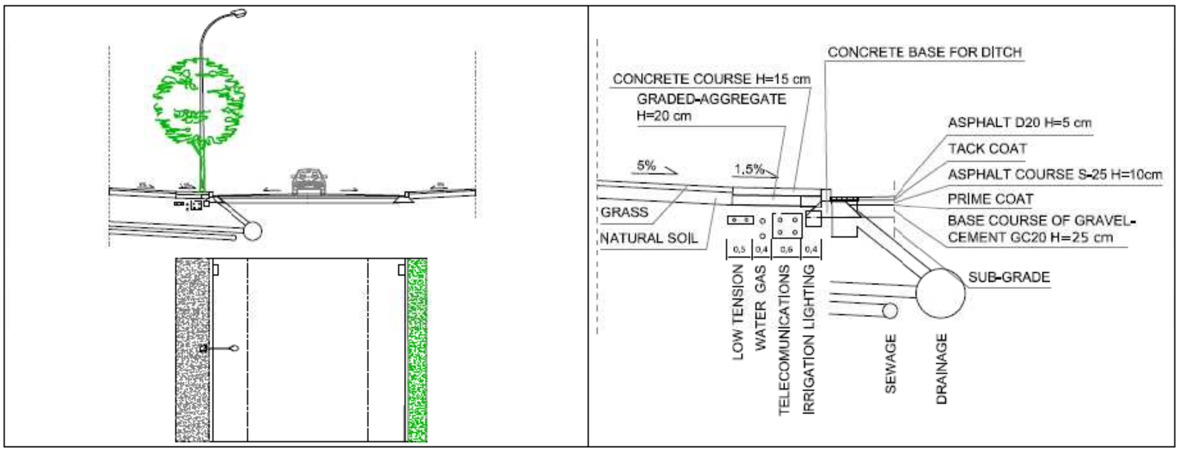


Pattern		C1	**Roadway structure**	**Asphalt D-20 (cm)**	5
Street type		street		**Asphalt S-25 (cm)**	10
Lighting	**Distribution**	staggered		**Gravel-cement GC20 (cm)**	25
	Height (m)	8	**Sidewalk structure**	**Concrete (cm)**	15
	Distance (m)	20		**Graded-aggregate (cm)**	20
	Power (W)	150		**Kerb type**	concrete
	Section	troncoconic	**Drainage tube material**		concrete
	Lamp	HPSSL	**Sewage tube**	**D = 300 mm**	PVC
Tree	**Type**	Pyrus communis	**Drinking water tube material**		polyethylene
	Average distance (m)	8.8			





Pattern		C2	**Roadway structure**	**Asphalt D-20 (cm)**	6
Street type		avenue		**Asphalt S-25 (cm)**	12
Lighting	**Distribution**	bilateral		**Gravel-cement GC20 (cm)**	25
	Height (m)	10		**Graded-aggregate (cm)**	30
	Distance (m)	27	**Sidewalk structure**	**Concrete (cm)**	15
	Power (W)	250		**Graded-aggregate (cm)**	20
	Section	troncoconic		**Kerb type**	concrete
	Lamp	HPSSL	**Drainage tube material**		concrete
Tree	**Type**	Pyrus communis	**Sewage tube**	**D = 300 mm**	PVC
	Average distance (m)	6.21	**Drinking water tube material**		polyethylene



Pattern		C2	**Roadway structure**	**Asphalt D-20 (cm)**	5
Street type		local street		**Asphalt S-25 (cm)**	10
Lighting	**Distribution**	unilateral		**Gravel-cement GC20 (cm)**	25
	Height (m)	10	**Sidewalk structure**	**Concrete (cm)**	15
	Distance (m)	27		**Graded-aggregate (cm)**	20
	Power (W)	250		**Kerb type**	concrete
	Section	troncoconic	**Drainage tube material**		concrete
	Lamp	HPSSL	**Sewage tube**	**D = 300 mm**	PVC
Tree	**Type**	-	**Drinking water tube material**		polyethylene
	Average distance (m)	-			

6.4 Buildings

Buildings entails one of the most harmful impacts on the environment, they consume 32% of the world's resources, besides the use of 12% of the global water consumption and up to 40% of the global energy consumption. Households are responsible of about 40% of the global waste generally stored on landfills and 40% of the total greenhouse gas emissions (World Green Building Council, 2009).

Generally buildings are constructed with very energy intensive materials such as steel, glass and concrete which for its execution may cause severe environmental impacts. Furthermore, with the current world's growing population those materials are in shortening supply.

Even though the large commercial buildings have been labeled as the most resources and energy consumption for their sub- and super-structures is important to note that the vast majority of the buildings, for instance those destined for residential purposes, requires a number of materials which can be as important to consider as the commercial ones.

When it comes to assess the building initial embodied energy and initial embodied CO_2 emissions there are different proposes depending of author's preferences and background. One way of break up the assessment into subgroups is to subdivide by structural and non-structural components. In that case, literature has review that the structure accounts for an average of 43% of the initial embodied energy, while the non-structural components, including finishes materials accounts for 57% of the embodied energy. That can be justified because. On the one hand, though the structure entails a main part of the initial embodied energy it last for the entire life span of the building, and on the other hand, the non-structural components requires long and short term refurbishment and maintenance (Buchanan, A., and Honey, B. G., 1994), (Aye, L., Bamford, N., Charters, B. and Robinson, J., 2000) (Cole, R. J., & Kernan, P. C., 1996).

Other authors have broken down the assessment of embodied energy into the following individual components: structure, foundations, internal and external enclosures, and finishes.

Treloar et al (2001) stated that structural embodied energy accounts from 64% up to 90% of the total embodied energy, while finishes range from 6% to 8% (Treloar, G. J., Fay, R., Ilozor, B. and Love, P. E. D., 2001).

In this study the components chosen to assess energy consumption and carbon dioxide emissions, concerning a civil engineering point of view, have been earthworks, foundations and frame structure.

The excavation works accustoms to be very energy intensive in the construction stage due to the high usage of heavy machinery, for digging, soil loading and transport. In the current paper the earthworks have been considered for basement digging and excavation for trench foundations.

Regarding the frame structure has been considered two typologies. The first one is reinforced concrete for all the buildings but the case of *reticular detached houses* that is formed by timber structure.

In general terms the building types considered in this study model by model are:

MODEL	BUILDING type	FRAME STRUCTURE	FLOORS	BASEMENTS
A1	residential street	reinforced concrete	1st floor + 4	1
	residential avenue	reinforced concrete	1st floor + 9	3
A2	residential street	reinforced concrete	1st floor + 5	2
B1	residential tower	reinforced concrete	1st floor + 29	3
	residential tower	reinforced concrete	1st floor + 29	4
	residential tower	reinforced concrete	1st floor + 29	5
	equipment	reinforced concrete	1st floor + 3	3
	commercial	reinforced concrete	ground floor	3
	commercial	reinforced concrete	ground floor	4
	commercial	reinforced concrete	ground floor	5
B2	residential	reinforced concrete	1rst floor + 5	-
	residential	reinforced concrete	1st floor + 11	-
	residential	reinforced concrete	1st floor + 15	-
	equipment	reinforced concrete	1st floor + 15	-
	commercial	reinforced concrete	1rst floor + 5	-
C1	residential	Timber	1st floor + 1	-
C2	residential	reinforced concrete	1st floor + 2	-

TABLE 15. Building features.

6.4.1 *Frame structure estimation*

The piers that forms the vertical faces of the frame structure has been estimated by the load that would support each pier following the formula below.

$$\gamma_l \cdot A \cdot L = \frac{R}{\gamma_c} \cdot S$$

Where:

γ_l: Is the load safety factor (1.5)

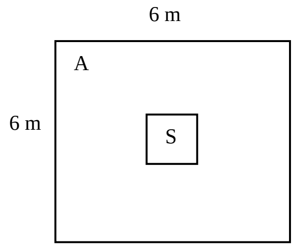
A: Area where the load acts

L: Design load (600 kg/m^2)

R: Concrete resistance (25 MPa)

γ_c: Concrete safety factor

S: Pier section



Putting in the state values:

$$1.5 \cdot 6m \cdot 6m \cdot 600\,\frac{kg}{m^2} = \frac{250\,\frac{kg}{m^2}}{1.35} \cdot S$$

So we may see that the left side of the formula above means the load transferred to the pier for each floor assuming an average distance between piers of 6 meters. Therefore, the floor load will be:

$$1.5 \cdot 6m \cdot 6m \cdot 600\,\frac{kg}{m^2} = 32400\,kg$$

Isolating the value of S we obtain S = 238.14 cm^2. Considering a square section we get S = 15.4x15.4 cm^2. For constructive reasons the minimum section will be S = 30x30 cm^2.

Next we are going to calculate the piers section in function of the height by the same processes, multiplying the floor load times the number of floors and isolating the value of S, Finally the value "a" means the dimension of the square side.

Floors	**Load (kg)**	**S (cm)**	**a (cm)**	**Final design**
5	162000	874.8	29.58	30x30 cm
10	324000	1749.6	41.83	45x45 cm
15	486000	2624.4	51.23	55x55 cm
20	648000	3499.2	59.15	60x60 cm
25	810000	4374	66.14	65x65 cm
30	972000	5248.8	72.45	70x70 cm
35	1134000	6123.6	78.25	80x80 cm

TABLE 16. Piers final design.

Regarding the reinforced concrete slabs for floors, it has been considered two thicknesses, one of 25 cm of reticular ribbed framework plus 5 cm of mortar for residential floors, and one of 35 cm of reticular ribbed framework plus 5 cm of mortar for parking basements. Both of them are available in the construction market.

The single family houses of reinforced concrete frame structure have been considered with piers of 20x20 cm. And finally, the single family houses made of timber have been adopted as shows the following sketch with piers of 20x20 cm while beams of 10x20 cm.

7 RESULTS

7.1 Measurements model by model

7.1.1 *Drainage system*

The measurements of the drainage system are given in meters and classified according the diameters of the pipes. There is constructed a manhole every 50 meters of longitudinal pipeline in average. The following table shows the drainage system measurements.

Model	Length by diameters (m)								Total length (m)	Manholes
	40 cm	50 cm	60 cm	80 cm	100 cm	120 cm	140 cm	160 cm		
A1 Manhattan	2243.33	1864.8	2242.9	158.5	317	475.5	376.43	12.56	7691.02	153
A2 Barcelona	3728	1596	1151	1064	162.6	133	133	18	7985.6	159
B1 Hong Kong	4683.5	580	943	436	698	260	4.5	-	7605	152
B2 Moscow	2022.86	1387.96	344.2	350.25	414	809.7	-	15	5343.97	106
C1 Chicago	450.1	520.8	1046.5	2206.8	76	-	228	84	4612.2	92
C2 Los Angeles	564.04	504.2	681.72	198.12	898	108	101.6	-	3055.68	61

TABLE 17. Drainage system measurements.

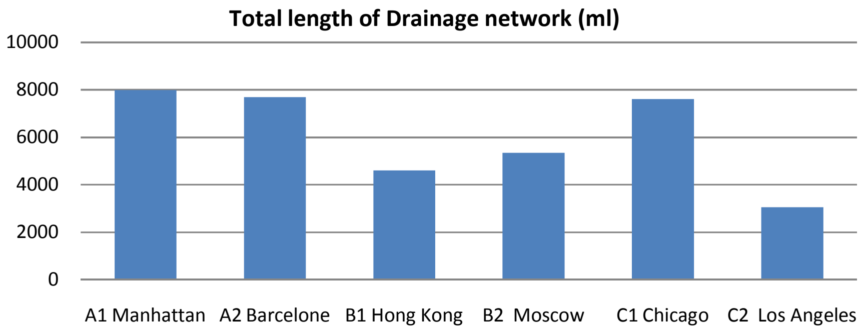


FIGURE 19. Drainage system length of each model.

Clearly the drainage length depends upon: how much gridded is the street layout, the fragmentation of the drainage basins and the branching for façade. So, Los Angeles with tree-like street layout has much less length than Chicago, completely reticulated; at the same time, Los Angeles, with a land use distribution similar to Moscow, has less network due to its lower drainage basin fragmentation; and finally, Barcelona has a bit more drainage length due to the branching of the network following both street façade alignments separated 20 m.

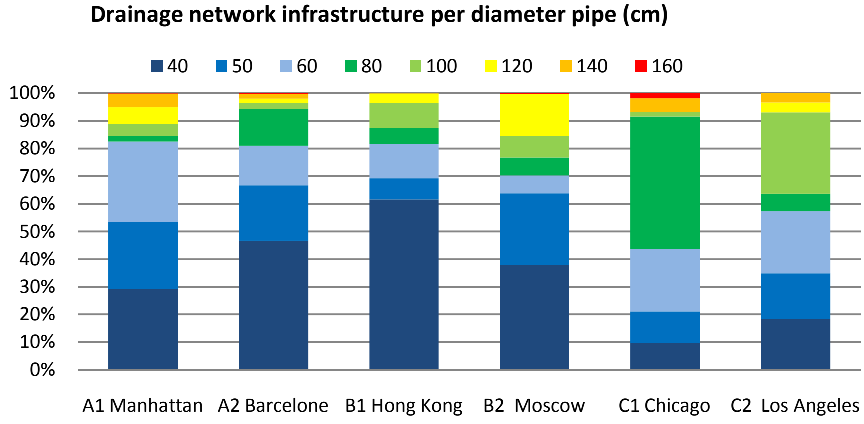


FIGURE 20. Share of drainage system diameters.

The section distributions of the network depends on its own structure (tree-like or grid), of the land uses (The vegetation reduce the runoff flows) and the branching of the network by facades. The difference is small between Chicago and Los Angeles in terms of medium network; or between Chicago and Barcelona due to the green area, even having a similar reticular layout; finally, is also remarkable the difference between the grid of Manhattan and Barcelona in terms of the length of the largest sections.

7.1.2 *Drinking water*

The measurements of the drinking water system are given in meters and classified according the diameters of the pipes. There is constructed a manhole every 50 meters of longitudinal pipeline in average as well. The following table shows the drinking water system measurements.

Model	Length by diameters (m)		Total length (m)
	110 mm	160 mm	
A1 Manhattan	0	9169.6	9169.6
A2 Barcelona	0	8088.64	8088.64
B1 Hong Kong	0	4080.9	4080.9
B2 Moscow	0	5747.4	5747.4
C1 Chicago	9744	0	9744
C2 Los Angeles	5279.4	0	5279.4

TABLE 18. Drinking water measurements.

The length of the drinking water system depends, in a decreasing meaning, of how much hierarchical is the street layout, and in turn of how much rectangular is the urban grid and also is related with the urban fabric size or the pattern.

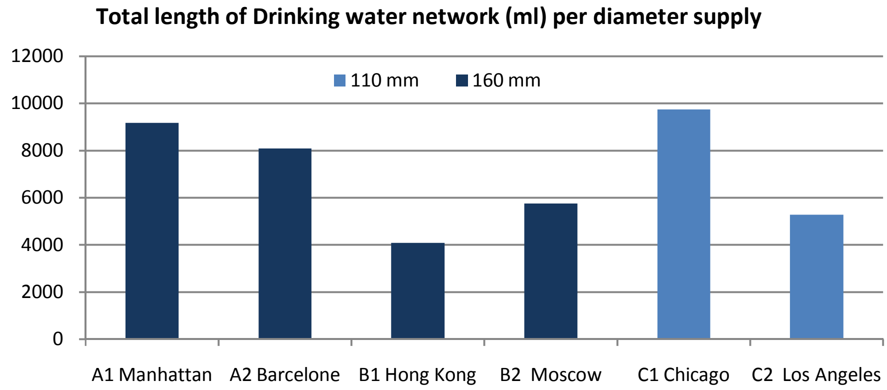


FIGURE 21. Length of the drinking water system model by model.

7.1.3 *Sewage system*

The sewage system measurements are shown below following the same criteria as the both above that are classified according the length of the pipe with the same diameter. The manholes again, are constructed every 50 meters in average in order to provide access to the network for workers in case of failure.

Model	Length by diameters (m)			Total length (m)	Manholes
	30 cm	40 cm	50 cm		
A1 Manhattan	9099.6	-	13.78	9113.38	182
A2 Barcelona	7166.8	151	-	7317.8	146
B1 Hong Kong	4080.9	281.7	141.9	4504.5	90
B2 Moscow	5747.4	-	-	5747.4	114
C1 Chicago	6297.5	-	-	6297.5	125
C2 Los Angeles	5279.4	-	-	5279.4	105

TABLE 19. Sewage system measurements.

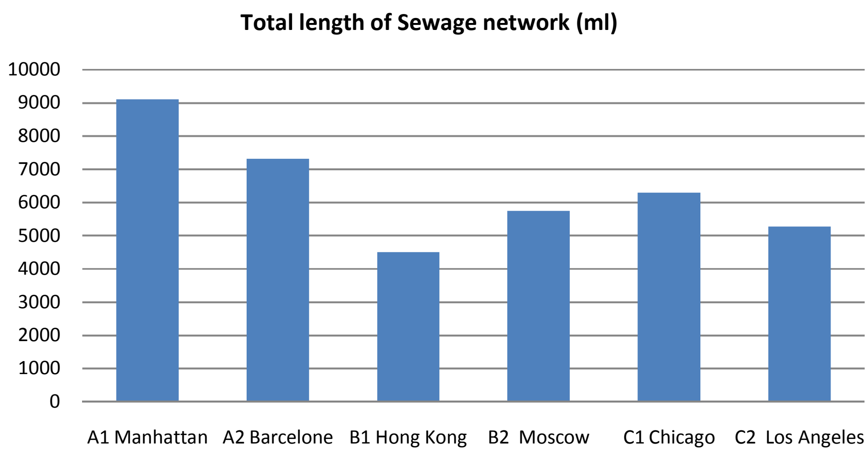


FIGURE 22. Total length of the sewage system per model.

The length of the sewage system depends, in practice, of the same factors than the drainage system.

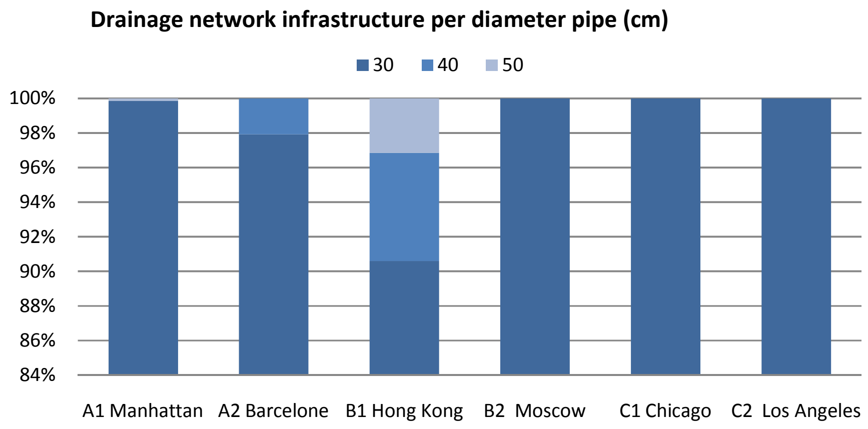


FIGURE 23. Share of each diameter of the sewage system per model.

The section structures is much more simple that the rain water; here the flows are much smaller and require less to change to larger diameters.

7.1.4 *Public lighting*

The public light measurements are collected in the following table, model by model ant for the road category and functionality. The features shown are the roadway with which have to illuminate, the lamp-post distribution, the column height, the distance between lamp-posts and the bulb potency. Additionally, it is shown the total length that each network covers and the total number of lamp post placed.

Model	Road category	Roadway width (m)	Lamp-posts distribution	Lamp-post height (m)	Lamp-post separation (m)	Bulb power (W)	Length (m)	Number of Lamp-posts
A1 Manhattan	Avenue	18	bilateral	10	27	250	1902	141
	Street	9	staggered	8	20	150	3618	181
A2 Barcelona	Street	10	staggered	8	20	150	4920	246
B1 Hong Kong	Avenue	18	bilateral	10	27	250	1860	69
	Collector	9	staggered	8	20	150	717.2	36
	Local	7	staggered	6	15	100	498.4	33
	Allée	C=20, A=12	bilateral	6	20	100	1078.8	108
	Promenade1	C=16, A=7	staggered	6	15	100	191.4	13
	Promenade2	C=10, A=7	unilateral	8	20	150	880	44
	Pedestrian	6	unilateral	6	16	100	659.2	41
B2 Moscow	Avenue	21	bilateral	10	27	250	1281	95
	Collector	6	unilateral	6	15	100	2921.2	195
	Parking 1	16	bilateral	8	20	150	1883.6	188
	Access	6	unilateral	6	15	100	1760	117
	Parking2	11	staggered	8	20	150	92	5
	Path	2	unilateral	3	10	70	3712.6	371
C1 Chicago	Avenue	11	staggered	10	25	250	2280	91
	Street	9	staggered	8	20	150	3696	185

C2 Los Angeles	Avenue	24	bilateral	10	27	250	462.6	34
	Local	10.5	unilateral	10	27	250	2693.7	100

TABLE 20. Public lighting measurements.

The lighting measurements depend on: the type and height of the lamp-post that holds the luminary; the continuity of the streets of the grid; the typology of the lighting in relation of roadway-sidewalk and the street trees. It is estimated that the lack of maintenance and an adequate pruned, to provide a determined form, is the cause that the light intensity does not reach the street floors in dense cities.

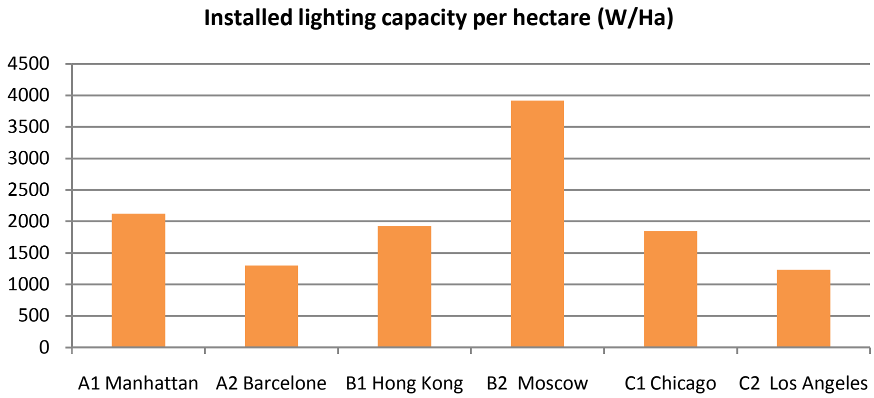


FIGURE 24. Installed lighting capacity.

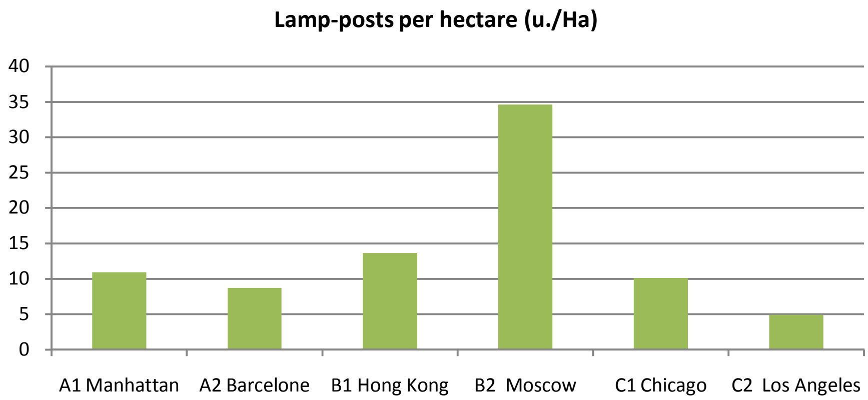


FIGURE 25. Number of lamp-post per hectare.

7.1.5 *Tree alignment*

The street trees are composed by four different types as it is shown in the following table eith its total amount planted in each model.

Model	Tree specie	Quantity
A1 Manhattan	Pyrus communis	400
A2 Barcelona	Platanus Hispanica	360
B1 Hong Kong	Koelreuteria paniculata	176
B2 Moscow	Alnus glutinosa	876
C1 Chicago	Pyrus communis	968
C2 Los Angeles	Pyrus communis	136

TABLE 21. Tree measurements.

7.2 Results of energy consumption and CO2 emissions

The structure of the presentation of the results consists basically in two main parts. The first one, give the results of the public infrastructure impact throughout two stages, firstly during the material manufacturing and secondly due to the installation works. The second main part, contains the results of the building contribution, again during the material manufacturing and assembling stages. The results always expressed per hectare and per inhabitant.

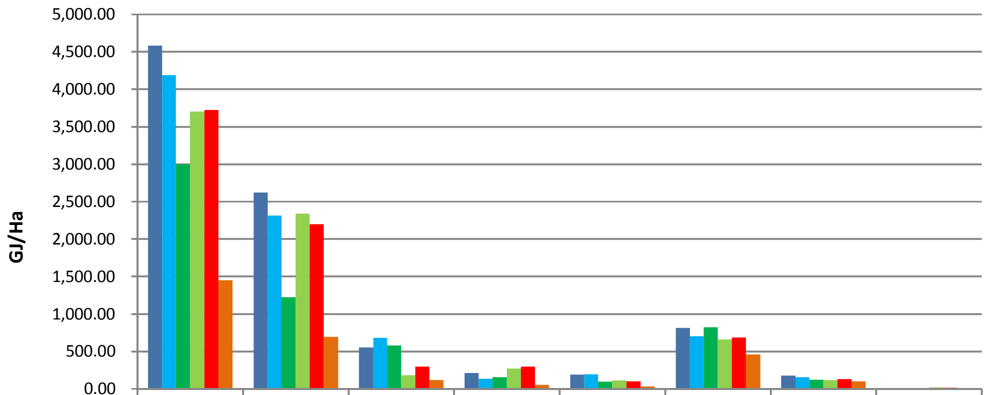
7.2.1 *Public infrastructure*

The results of the public infrastructure are given in two parts. The first one is the energy consumption due to material manufacturing, and the second one, the energy consumption result of installation works. Both parts of the results are expressed first per hectare and second per inhabitant.

7.2.1.1 Energy consumption in material manufacturing and construction stagesr hectare

The results of the manufacturing stage reveal that definitely the roadway infrastructure is taking the lead in terms of energy consumption, mainly due to the production of hot mix asphalt which requires high temperature processes. The second most contributing unit to energy consumption is the drainage system, due to the concrete pipelines manufacturing, followed by the sidewalk infrastructure on average. From the fourth to the sixth place are taken by the lighting, the drinking water system and sewage system leaving the last place for gardening that does not requires almost any manufacturing process. So, the bar chart below shows the gigajoules (1 gigajoule is equivalent to 1 billion joules) per hectare of each civil work unit.

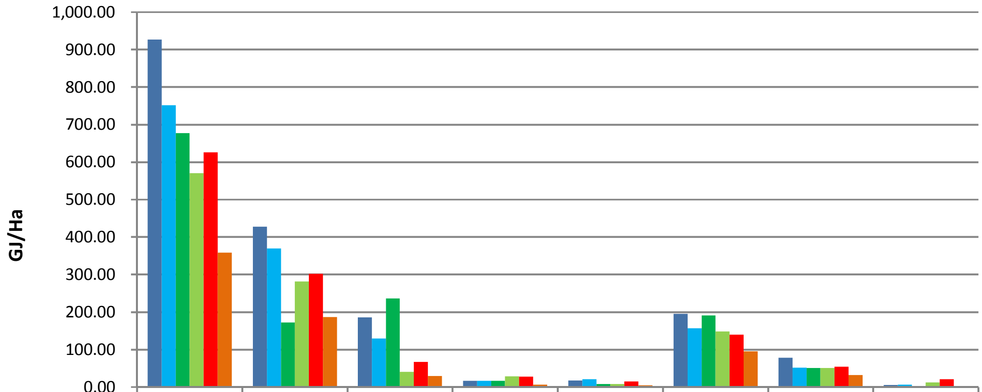
Regarding the patterns the A1 is taken the lead in terms of the total energy consumption for materials manufacturing followed by A2. So the two close fabrics occupy the first two positions. Next, we find the patterns C1 and B2 with similar impact. The next pattern is the B1 which have les length of public infrastructure. And finally, in the last position we have the fractal street layout model C2.



	TOTAL	ROADWAY	SIDEWALKS	LIGHTING	DRINKING WATER	DRAINAGE	SEWAGE	GARDENING
A1 (Manhattan)	4,583.11	2,620.58	554.16	214.08	190.78	816.79	179.52	7.20
A2 (Barcelone)	4,189.72	2,312.08	683.37	133.43	197.02	703.08	152.44	8.30
B1 (Hong Kong)	2,998.81	1,223.74	577.75	153.79	93.97	823.35	122.24	3.99
B2 (Moscow)	3,702.41	2,336.44	182.60	271.73	111.99	660.56	116.83	22.26
C1 (Chicago)	3,724.90	2,202.03	294.30	293.75	101.64	687.87	128.36	16.96
C2 (Los Angeles)	1,449.47	694.66	113.91	51.68	30.01	457.63	98.64	2.93

TABLE 22. Comparative energy consumption in civil work units per urban model in manufacturing stage (GJ/Ha)

The next bar chart with its matrix data contains the energy consumption due to installation works. The energy consumption of installation works is mainly due to machinery usage for digging, filling, compacting, picking and transport. The roadway is still taking the lead although with less advantage. There is a notable contribution in drainage piping installation and sidewalks construction. It is important to note that the increase of drainage system is mainly due to the large trench dimensions, and in turn the amount of digging works that this network requires. Sewage has a remarkable impact while lighting, drinking water and gardening have less contribution.

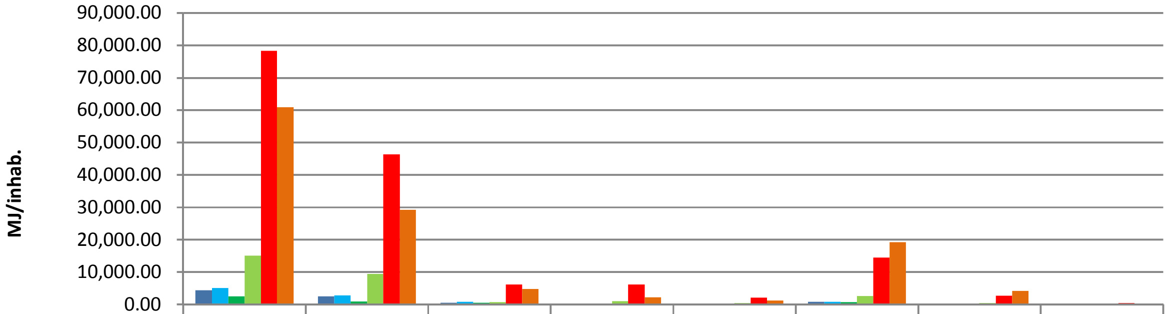


	TOTAL	ROADWAY	SIDEWALKS	LIGHTING	DRINKING WATER	DRAINAGE	SEWAGE	GARDENING
A1 (Manhattan)	926.76	428.03	185.14	16.34	17.26	195.89	78.21	5.89
A2 (Barcelone)	752.35	369.55	129.65	16.30	21.08	157.20	51.78	6.80
B1 (Hong Kong)	676.86	172.34	235.94	16.40	8.29	191.01	50.37	2.50
B2 (Moscow)	570.64	282.36	40.95	28.42	8.39	147.73	50.58	12.19
C1 (Chicago)	626.10	302.35	67.74	27.32	14.63	139.36	54.21	20.49
C2 (Los Angeles)	358.29	187.39	29.48	6.26	5.31	95.27	32.19	2.40

TABLE 23. Comparative energy consumption in civil work units per urban model in construction stage (GJ/Ha)

7.2.1.2 Energy consumption in material manufacturing and construction stages per inhabitant

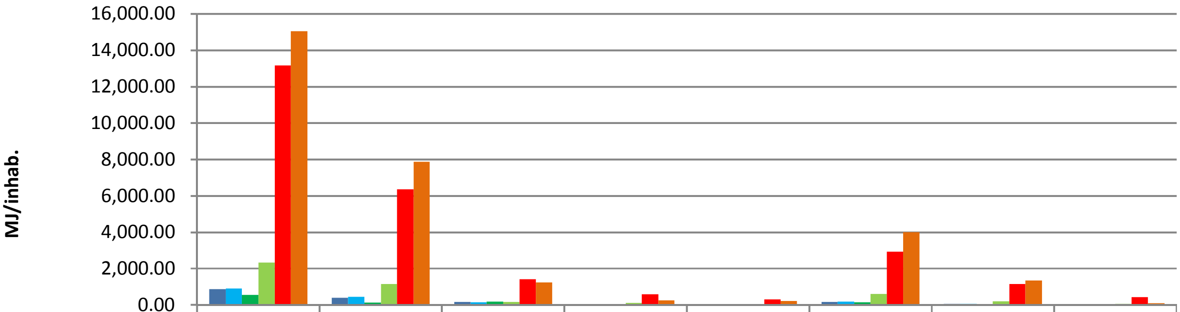
If we take into consideration the number of inhabitants housing each pattern the scenario change completely. We may see now that the low-density patters C1 and C2 take the lead resoundingly in what material manufacturing refers (see table below). Also the pattern B2 have a significant impact per inhabitant but still not comparable with the two firsts. In is worth to stress now that the units are given in megajoules (1 megajoule is equivalent to 1 million of joules) per inhabitant.



	TOTAL	ROADWAY	SIDEWALKS	LIGHTING	DRINKING WATER	DRAINAGE	SEWAGE	GARDENIN G
A1 (Manhattan)	4,327.91	2,474.66	523.30	202.16	180.15	771.30	169.53	6.80
A2 (Barcelone)	5,146.67	2,840.17	839.45	163.91	242.02	863.66	187.25	10.20
B1 (Hong Kong)	2,467.87	1,007.07	475.46	126.56	77.33	677.57	100.60	3.28
B2 (Moscow)	15,102.74	9,530.73	744.85	1,108.45	456.81	2,694.54	476.56	90.80
C1 (Chicago)	78,347.11	46,316.03	6,190.12	6,178.54	2,137.73	14,468.16	2,699.79	356.74
C2 (Los Angeles)	60,913.22	29,192.86	4,787.01	2,171.83	1,261.07	19,231.75	4,145.38	123.33

TABLE 24. Comparative energy consumption in civil work units per inhabitant in manufacturing stage (MJ/Ha)

When it comes to energy consumption due to construction works the scenario it is almost repeated keeping in the highest positions the low-density unban structures.

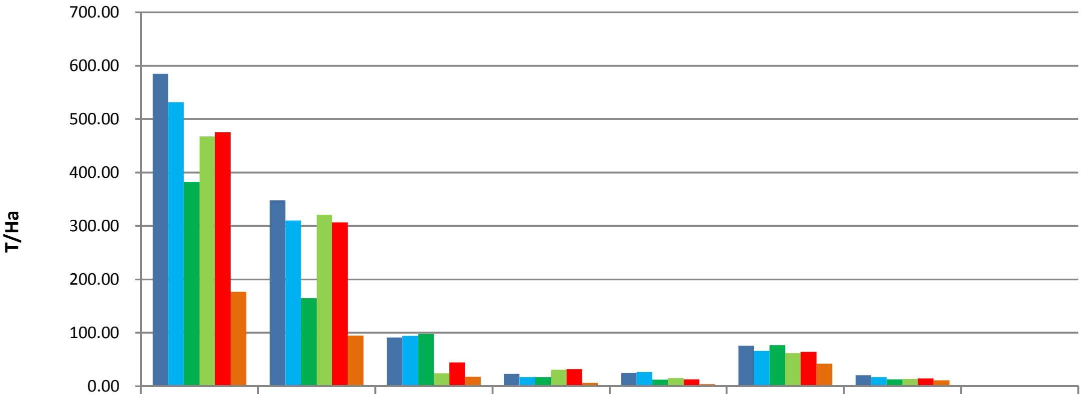


	TOTAL	ROADWAY	SIDEWALKS	LIGHTING	DRINKING WATER	DRAINAGE	SEWAGE	GARDENING
A1 (Manhattan)	875.16	404.20	174.83	15.43	16.30	184.98	73.86	5.57
A2 (Barcelone)	924.19	453.95	159.26	20.02	25.90	193.10	63.61	8.35
B1 (Hong Kong)	557.02	141.83	194.17	13.49	6.83	157.19	41.45	2.06
B2 (Moscow)	2,327.73	1,151.80	167.05	115.95	34.24	602.63	206.34	49.73
C1 (Chicago)	13,168.99	6,359.38	1,424.70	574.73	307.82	2,931.20	1,140.15	431.01
C2 (Los Angeles)	15,057.08	7,875.15	1,238.71	262.91	222.95	4,003.69	1,352.75	100.92

TABLE 25. Comparative energy consumption in civil work units per inhabitant in construction stage (MJ/Ha)

7.2.1.3 Carbon dioxide emissions in material manufacturing and construction stages per hectare

Firstly, it is shown the resulting CO_2 emissions due to the material manufacturing stage mainly because of the emissions for power generation and transport of the raw materials to the industry. The next char bar has the units of metric tons per hectare of pattern.

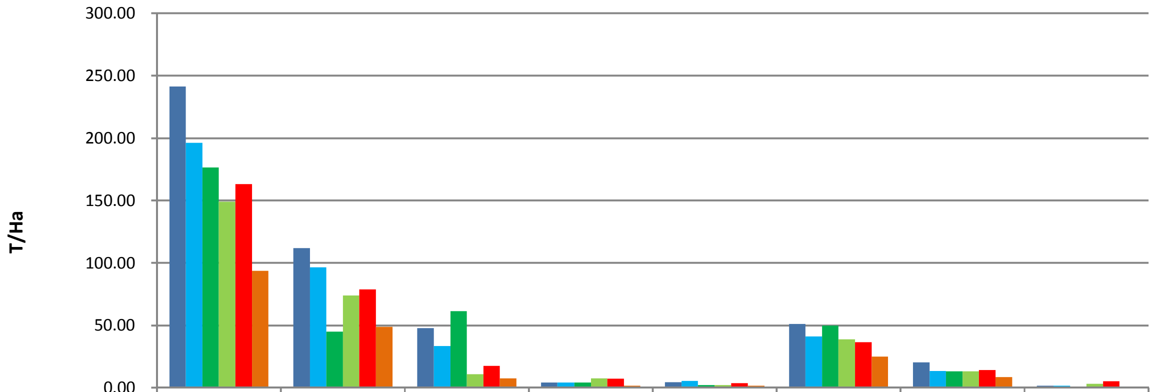


	TOTAL	ROADWAY	SIDEWALKS	LIGHTING	DRINKING WATER	DRIANAGE	SEWAGE	GARDENING
A1 (Manhattan)	584.52	347.79	91.62	23.44	24.82	75.95	20.12	0.77
A2 (Barcelone)	531.42	310.15	94.27	16.98	26.63	65.56	16.95	0.89
B1 (Hong Kong)	382.58	164.97	97.88	16.86	12.56	76.96	13.15	0.21
B2 (Moscow)	467.54	320.82	24.50	30.89	15.35	61.68	13.11	1.19
C1 (Chicago)	475.12	306.55	44.17	32.00	12.91	64.17	14.41	0.90
C2 (Los Angeles)	177.35	94.97	17.58	6.51	4.16	42.48	11.34	0.31

TABLE 26. Comparative CO_2 emissions in civil work units per urban model in manufacturing stage (Tons/Ha)

As we may appreciate, again the production of hot mix asphalt and bitumen aggregates takes the lead in terms of environmental impact. However the drainage system and sidewalks have a comparable effect with the roadway.

The contribution to the CO_2 emission through the construction stage it is shown in the following table. In general terms, looking at the total column it is found to be half of the contribution due to the material manufacturing stage. Here, the CO_2 emissions are caused by machinery usage for digging, filling, compacting, picking and transport of the civil works.

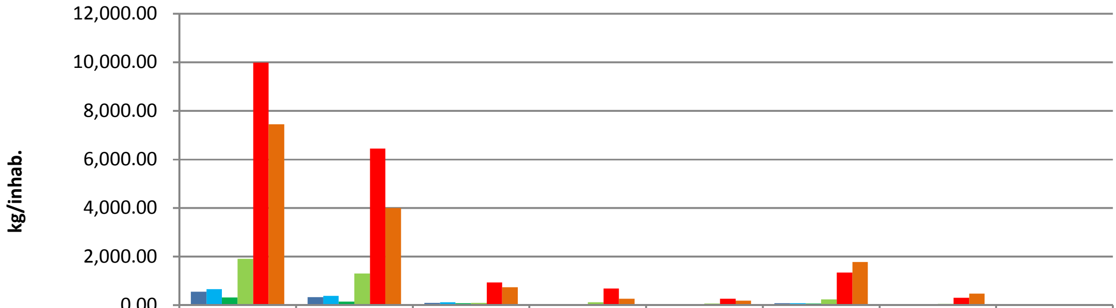


	TOTAL	ROADWAY	SIDEWALKS	LIGHTING	DRINKING WATER	DRIANAGE	SEWAGE	GARDENING
A1 (Manhattan)	241.46	111.80	47.75	4.27	4.51	51.16	20.43	1.54
A2 (Barcelone)	196.07	96.50	33.45	4.26	5.51	41.06	13.52	1.78
B1 (Hong Kong)	176.55	45.02	61.39	4.28	2.17	49.89	13.16	0.65
B2 (Moscow)	149.04	73.75	10.70	7.42	2.19	38.59	13.21	3.18
C1 (Chicago)	163.31	78.97	17.47	7.14	3.82	36.40	14.16	5.35
C2 (Los Angeles)	93.49	48.95	7.60	1.63	1.39	24.88	8.41	0.63

TABLE 27. Comparative CO_2 emissions in civil work units per urban model in constructing stage (Tons/Ha)

7.2.1.4 Carbon dioxide emissions in material manufacturing and construction stages per inhabitant

The current section present the results obtained of the CO_2 emissions during the material manufacturing stage per inhabitant. Again, when we reflect the release of CO_2 per inhabitant the scenario changes completely. Regarding the public infrastructure here, the highest release of CO_2 is caused by the C1 (Chicago) pattern, while the lowest is the pattern B1 (Hong Kong) due to the low percentage of public infrastructure per inhabitant. Note here that the results are given in kilograms of CO_2 per inhabitant.

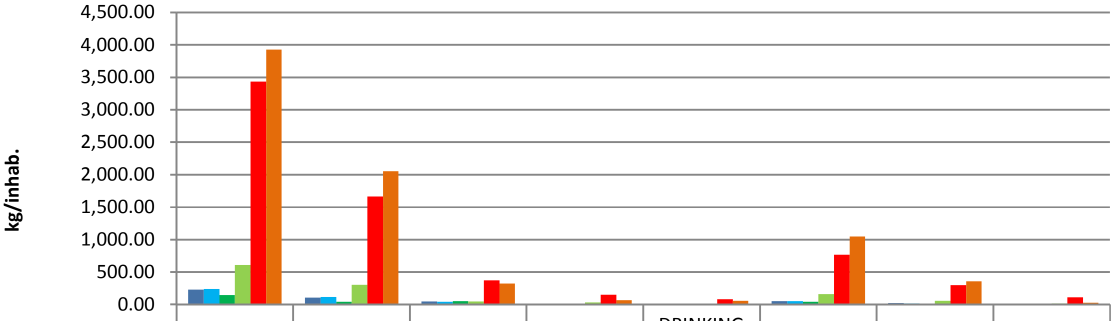


	TOTAL	ROADWAY	SIDEWALKS	LIGHTING	DRINKING WATER	DRIANAGE	SEWAGE	GARDENING
A1	551.97	328.42	86.52	22.14	23.44	71.72	19.00	0.73
A2	652.80	380.99	115.80	20.86	32.71	80.54	20.82	1.09
B1	314.85	135.76	80.55	13.87	10.33	63.33	10.82	0.17
B2	1,907.17	1,308.70	99.92	126.02	62.60	251.61	53.48	4.84
C1	9,993.28	6,447.68	929.15	672.99	271.60	1,349.78	303.07	19.02
C2	7,453.00	3,990.90	738.61	273.64	174.96	1,785.29	476.38	13.22

TABLE 28. Comparative CO_2 emissions in civil work units per urban model in manufacturing stage (kg/inhabitant)

The release of CO_2 during the construction works is roughly half of the material manufacturing stage for all the models.

The following graph belongs to the results of CO_2 emissions during the construction stage given in Kilograms per inhabitant.



	TOTAL	ROADWAY	SIDEWALKS	LIGHTING	DRINKING WATER	DRIANAGE	SEWAGE	GARDENING
A1	228.02	105.58	45.10	4.03	4.26	48.31	19.29	1.45
A2	240.86	118.54	41.10	5.23	6.76	50.44	16.61	2.18
B1	145.29	37.05	50.52	3.52	1.78	41.05	10.83	0.54
B2	607.97	300.85	43.63	30.28	8.94	157.40	53.89	12.99
C1	3,435.00	1,661.07	367.49	150.12	80.40	765.58	297.76	112.58
C2	3,928.74	2,056.99	319.52	68.67	58.23	1,045.70	353.26	26.36

TABLE 29. Comparative CO_2 emissions in civil work units per urban model in construction stage (kg/inhabitant)

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