POLITECNICO DI TORINO

Master Degree - Civil Engineering

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# URBAN-SCALE DIGITAL TWIN FOR A MASTER PLAN IN THE AREA ADJACENT TO THE INTERNATIONAL AIRPORT OF CEBU' – PHILIPPINES

**Supervisor:**

*Prof.ssa Anna Osello*

**Correlator:**

*Prof.ssa Francesca Ugliotti*

*Ing. Giuliano Pairone*

**Candidate:**

*Daniele Iunti*

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The present research is the result of a multidisciplinary study that brings together the skills derived from the civil engineering and automotive engineering courses of study. Within this specific thesis paper analyses, reasoning, and results are presented, mainly in the civil engineering field of investigation, with specific insights into the automotive sector. Despite the multifaceted nature of the research, the result the team achieved after one year of intense study is unique and derives from the collaboration and integration of competences from the abovementioned different backgrounds. This aspect represented the most challenging part of the study but at the same time the most enriching one, making it really interesting. As far as automotive engineering parts, engineer students in charge of these aspects are Ma Fanshu and Zhang Zheyuan. A special thank is a must because of their limitless availability and skills, methodological rigour and passion for the work done.

*“There is no logic that can be superimposed on the city;*
*people make it, and it is to them,*
*not buildings, that we must fit our plans.”*

— Jane Jacobs (1958)

Downtown is for people

## ABSTRACT

La popolazione umana ha impiegato 200.000 anni per raggiungere 1 miliardo e solo 200 anni per raggiungere i 7 miliardi. Con l’aumento della popolazione si sono sviluppate anche le città, con una domanda sempre crescente di una corretta gestione. In questo contesto, il progetto di tesi si propone di indagare l'approccio metodologico alla base dell'implementazione di un Digital Twin, sistema destinato a fornire una gestione intelligente, come parte di un master plan focalizzato sul miglioramento della mobilità urbana di una porzione limitata dell’isola di Mactan, Filippine. La tesi mirava a condurre un'analisi esaustiva della mobilità urbana nell'area circostante l'Aeroporto internazionale di Mactan. A tal fine sono state eseguite un'analisi preliminare di comprensione del sito e del sistema urbano, una valutazione degli itinerari comuni e delle deviazioni e la modellazione del Hub proposto per la mobilità. Di conseguenza, unendo i risultati delle indagini di ingegneria civile e gli esiti del settore automobilistico, la ricerca ha raggiunto un Digital Twin metodologico mostrando una possibile implementazione che affronti il problema della mobilità urbana dell'Isola. Dato il rapido sviluppo che le città stanno vivendo in termini di popolazione, dimensioni e consumi energetici, il Digital Twin metodologico fornito mira a migliorare la qualità della vita dei cittadini con l'ausilio delle tecnologie dell’industria 4.0. Questo fine viene perseguito affrontando alcuni dei diciassette obiettivi di sviluppo sostenibile dell'Agenda 2030 delle Nazioni Unite.

## ABSTRACT

Human population took 200,000 years to reach 1 billion and just 200 years to reach 7 billion. As population has grown, so have our cities, with an ever-increasing demand for proper management. In this context, the thesis project aims to investigate the methodological approach behind the implementation of a Digital Twin, system supposed to supply a smart management, as a part of a master plan focused on improving the urban mobility of a limited portion of Mactan Island, Philippines. The thesis aimed at carrying an exhaustive urban mobility analysis in the area surrounding the international Airport of Mactan. To this aim were performed a preliminary understanding analysis of the site and urban system, an assessment of common itineraries and path deviations, and the modelling of the proposed mobility Hub. As a consequence, merging results by civil engineering investigations and outcomes by automotive field, the research achieved a methodological Digital Twin showing a possible implementation addressing the urban mobility problem of the Island. Given the rapid development that cities are experiencing in terms of population, size and energy consumption, the methodological Digital Twin supplied aims to enhance citizens life quality with the help of industry 4.0 technologies. This objective is pursued addressing some of the seventeen sustainable development goals by the UN 2030 Agenda.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Global population growth

Modern humans evolved in Africa about 200.000 years ago. Migrations across the globe, about 100.000 years ago, started the phenomenon of population growth. With the advent of agriculture the growth increased and human population reached about 170 million people in 1 A.C. Nowadays, the modern society counts 7.8 billion people in 2021 [1] while the projection for 2050 peak at 9.7 billion people and, if the current trend continues, it will peak at 11,2 billion in 2100 [2]. From a historical perspective, population expansion has coincided with technological revolutions. In human history there have been three major technological revolutions, the tool-making revolution, the agricultural revolution, and the industrial revolution. Each revolution allowed humans a larger access to food resulting in consecutively population explosions.

### 1.1.1 Overpopulation

Global population dynamics and projections of growth presented lead to the introduction of the concept of overpopulation, whereby is meant a human population being too large in a way that the society and/or environment cannot readily sustain them. Overpopulation is argued to responsible for overconsumption and subsequently overshoot, when demand is in excess of regeneration capacity. This leads exceeding the carrying capacity of a geographical area and damaging the environment faster than it can be actually replenished.
Concern about overpopulation is an ancient topic, indeed, it has historically been seen as one of the greatest threats to humanity. This is still a current thought today. Moreover, the rapid increase in world population over the past three centuries, has increased awareness among some people that the Earth may not be able to sustain the future or even present number of its inhabitants. The eminent scientist and science writer *Isaac Asimov*, provided us with a good metaphor decades ago to help us visualise the issue:

*"[…] If two people live in an apartment, and there are two bathrooms, then both have freedom of the bathroom. You can go to the bathroom anytime you want, stay as long as you want, for whatever you need. And everyone believes in Freedom of the Bathroom; It should be right there in the Constitution. But if you have twenty people in the apartment and two bathrooms, then no matter how much every person believes in freedom of the bathroom, there's no such thing. You have to set up times for each person, you have to bang on the door, 'Aren't you through yet?' and so on. […] "* [3].

### 1.1.2 Urbanization

Population growing evolves into another global phenomenon that is urbanization. This phenomenon consists in people migration from the countryside, or rural areas, to more developed regions like towns and cities. Historically, this is motivated by the belief that urban areas have more to offer in terms of job opportunities, education, social services, political participation and finally a longer life expectancy. In 1960 the amount of people living in cities was 34% of the total. The percentage has continued to grow and in 2010 raised to 52% of the total. The United Nations indicates that, if the actual trend continues, by 2050 the 68% of world's population will be living in large cities covering less than 2% of the Earth's surface [4].

The chart in *Figure 1* [5] shows the increasing trend for people living in urban environment, highlighting the change in the rural and urban populations of the World from 2010 up to the projected figures for the year 2050 [4].

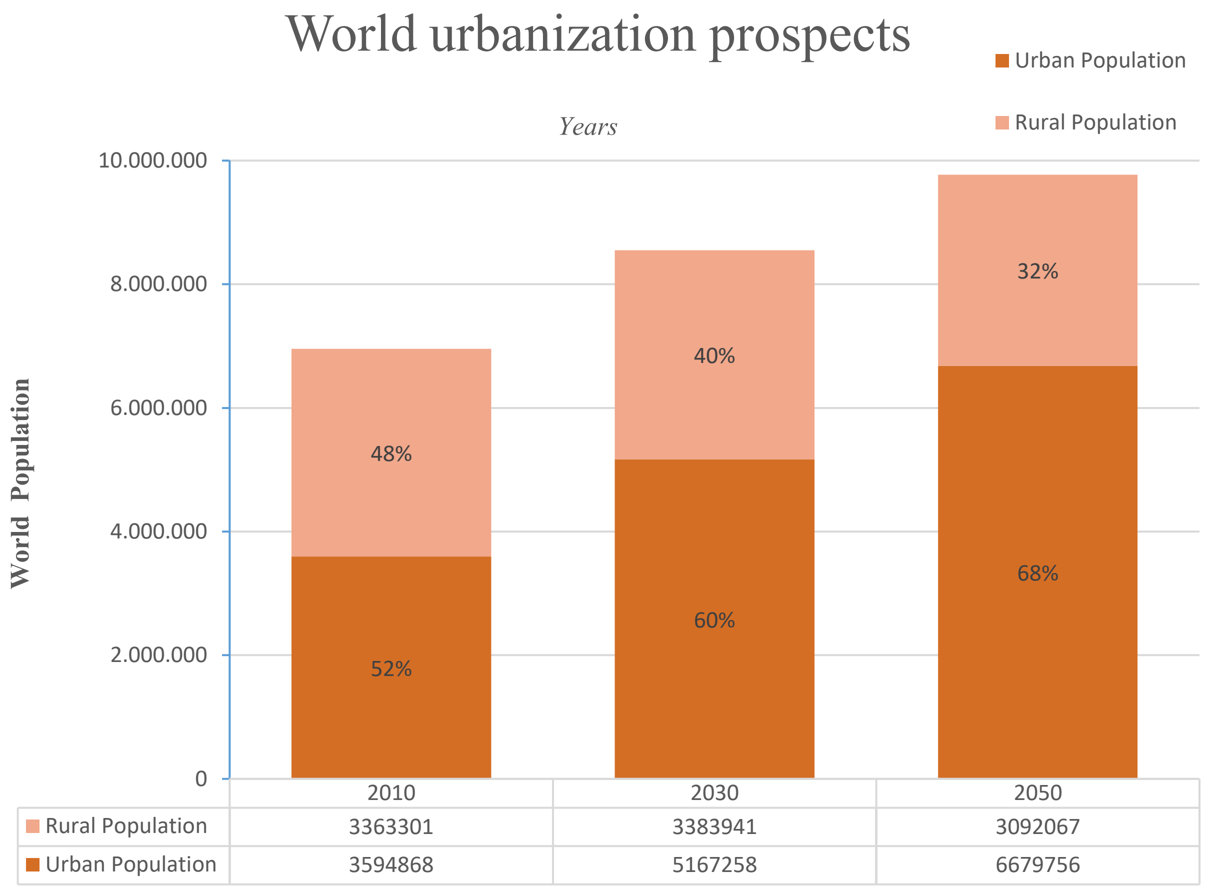



***Figure 1**: World Urbanization Prospects: The 2018 Revision.*

The main driven force for people migrating to larger urban agglomerates is the hope of gaining a better standard of living. The process of urbanisation affects all sizes of settlements, so villages gradually grow to become small towns, smaller towns become larger towns, and large towns become cities. The increase of population and the development of new infrastructures leads to rapid expansion of city borders which spread out and swallow up neighbouring urban areas. This trend increasingly causes the growth of mega-cities, whereby for mega-city is meant urban areas of greater than 10 million people living. In 1970 there were only three such agglomerates across the globe, but by the year 2000 the number had risen to 17. According to the projections performed by the Department of Economic and Social Affairs of United Nations, 24 more mega-cities will be added by the year 2030 [6].

The map presented in *Figure 2* was realized by UNESCO taking advantage of data supplied by UN DESA predictions about global population dynamics and projections of megacities growth in the world. [7] From the plotted predictions it is clear how urbanisation does not have the same trend in all parts of the Earth. In particular, for the considered period of time corresponding to 2018-2030, the map shows a more dramatic increase for poorest and least-urbanised continents, such as Asia and Africa, and for developing countries.

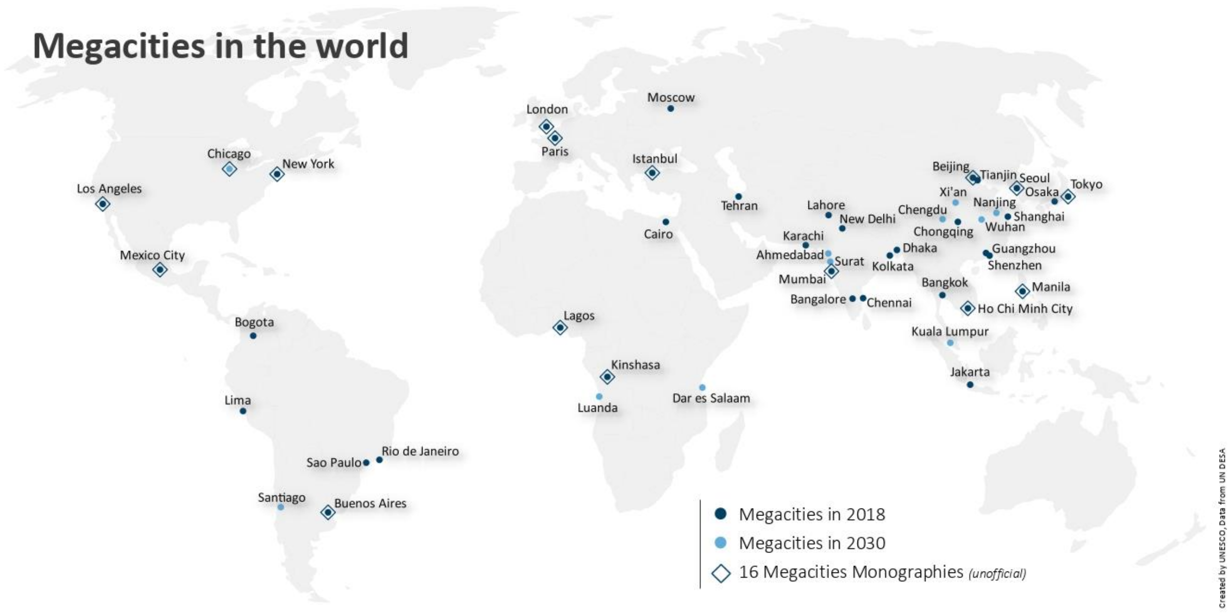



***Figure 2**: Megacities in the world*

Source: Megacities worldwide. UNESCO (2018)

### 1.1.3 Urban related issues

Population growth and large urban concentration have a significant impact on cities which were ever been so challenged. Trends of worldwide matter as the phenomena of urbanization, have the potential to become a positive driving force for every aspect of urban sustainable development. When properly planned and managed, urbanization can reduce poverty and inequalities, by increasing employment opportunities, and may improve life quality through better education and health services. But when poorly planned, urbanization can lead to higher crime rates, traffic congestion and pollution, increased levels of inequality and social exclusion. Overcrowded cities where many people spend their life in a limited space, not suitable to accommodate them, become crammed and unhealth. When a city gets beyond its carrying capacity, what happens is that people tend to compete over the limited and scarce sources such as food, water, transport, and the main reason they make a move, employment. From such conditions derive many urban-related issues of local and global concern, which are treated next one by one.
Theoretically speaking job opportunities should be greater in large cities, as well as paid more, but since the amount of people living in urban areas continues to grow, jobs risk to become even harder to find and retain. Consequentially, if the rate of unemployment increases, the rate of population poverty increases as well. As result of that, is true that cities are catalysts for economic growth, innovation and employment, however urban areas are more unequal than rural regions.
Moreover, overcrowded cities are exposed to serious housing problems. Indeed, if the urban environment is not well prepared to accommodate a large number of inhabitants, low-quality buildings supported by inadequate supply of public services arises. As a result of that, cities are not capable to guarantee a minimum quality of life for all urban residents and the community feeling of a city is reduced, while is promoted an inequal society with dissimilar urban areas in terms of incomes, available services, housing conditions and neighbourhood safety perceived by its inhabitants. Slums are the most visible symptom of exclusion in divided cities. The UN

DESA World Social Report 2020 about urbanization, reported an interesting picture on the proportion of urban population living in slums in developing countries in the period 1990-2014. According to UN-Habitat source data described in *Figure 3* [8], in absolute numbers Asia has the largest share of the world's slum population, with nearly 560 million people in 2014. Moreover, the World Social Report 2020 by UN DESA, the future of inequality will be determined by the urbanization process, whether this is harnessed and managed or whether it is allowed to feed growing divisions [8].

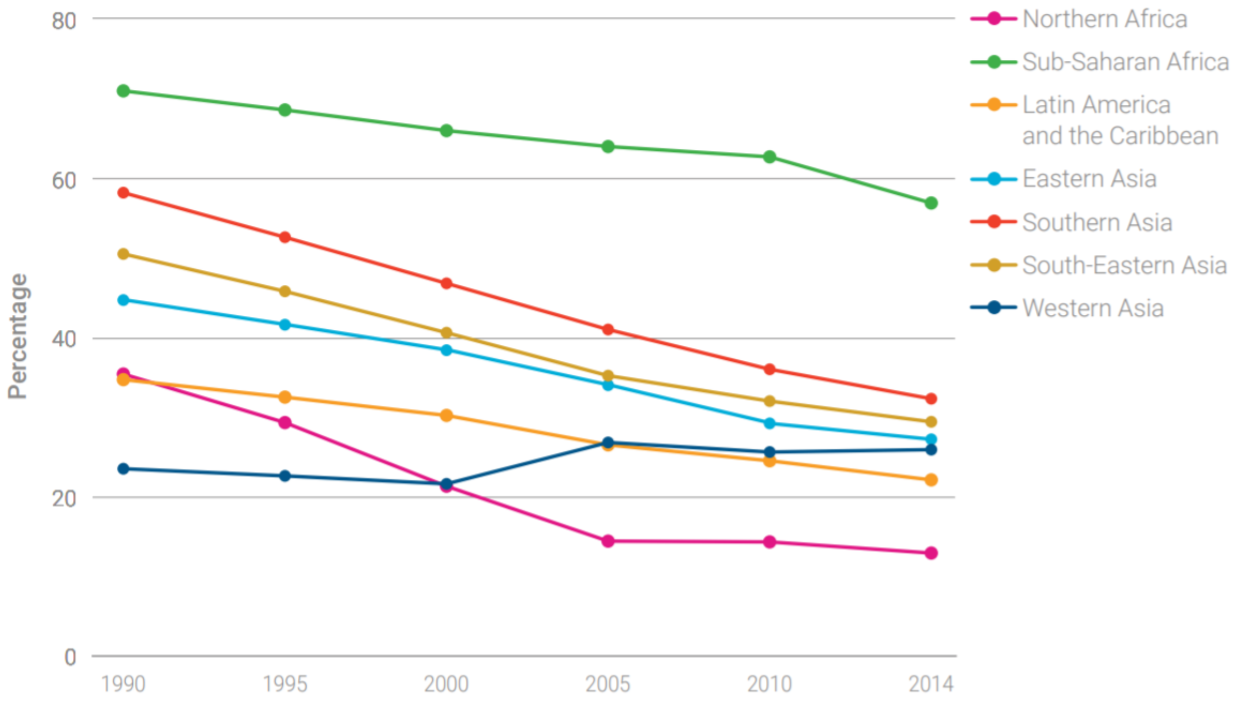



***Figure 3****: Proportion of urban population living in slums in developing countries. 1990-2014*

Source: UN-Habitat. World Social Report 2020: Inequality in a rapidly changing world. UN DESA (2016b)

Urbanization, but more in general the rampant growth in population, directly contributes to waste generation, making its proper disposal more and more an important challenge. If the tons of solid waste daily produced are not properly arranged and managed, the risk is to expose millions of citizens to disease of all kinds, which can then easily spread throughout the city and be harmful for human's health. With the onset of the Covid-19 pandemic health-related problems within large cities are even more obvious. Nowadays that the social distancing is the only effective measure to prevent virus sharing, the urbanization phenomenon and the concentration of people in cities has become one of the greatest health hazards of all times.
A steadily increase in urbanisation will result in a rampant consumption of energy by urban environments. After industrialisation, urbanisation is the second largest phenomenon to have a significant impact on energy consumption. It is known cities to consume the great majority of worldwide energy production, in between 60% and 80% [9]. Recently, it was conducted a study on the impact of urbanisation on energy consumption in China. The results of the analysis show as, for every 1% increase in the urban population relative to the total population, national energy consumption rose by 1.4%. The same study reports as urban households consume 50% more energy than rural households per capita, mainly because of energy-intensive lifestyles. Such impacting lifestyle is due to an increased energy consumption in new buildings and urban motorisation which increasingly requires intensive energy means of transport [10].

In 1994 the Inter Academy Panel about population growth announced as many environmental problems, such as rising levels of atmospheric carbon dioxide, global warming and pollution, are aggravated by the population expansion and urban concentration [11]. A more recent study conducted in 2018, describe cities as the greater producers of $CO_2$ emissions with a share in between the 60% and 80% of worldwide amount [9]. Many different sources contribute to pollution but however the main contribution is given by traffic. The transport sector handles the 23% of worldwide $CO_2$ emissions from fossil fuel combustion [12]. In other words, motor vehicles combustion gases cause a large part of pollution. As a result of that, since traffic level is highly influenced by urbanization and, moreover, in large cities people are moving in between their job places and homes in the same windows of time during the day, urban mobility becomes a true problem deserving attention. A not planned urban mobility results in traffic congestions which, on one side affect the efficiency of the city road network system, causing logistic delays due to traffic accidents into many drivers and pedestrians may be getting involved, while on the other side contribute to increase air and water pollution making grow the global level of environmental pollution. *Table 1* shows the $CO_2$ emissions per capita in tonnes of the ten largest metropolitan areas. These metropolises concentrate a sizable fraction of their country's total emissions, and data show sizable differences in the levels of total $CO_2$ per capita across these cities [13].

| Rank | Country | Metropolitan area | $CO_2$ emissions *per capita* (tonnes) | Share in country's total emissions | Share in country's total population |
|---|---|---|---|---|---|
| 1 | Japan | Tokyo | 7.55 | 22.47% | 26.64% |
| 2 | Korea | Seoul | 5.87 | 42.89% | 42.80% |
| 3 | Mexico | Mexico City | 3.17 | 12.59% | 18.86% |
| 4 | Japan | Osaka | 7.54 | 11.50% | 13.66% |
| 5 | United States | New York | 17.45 | 5.00% | 5.99% |
| 6 | United States | Los Angeles | 15.07 | 3.88% | 5.,38% |
| | | | | | |
| 8 | United Kingdom | London | 7.33 | 14.27% | 17.46% |
| 8 | France | Paris | 7.44 | 18.83% | 19.04% |
| 9 | United States | Chicago | 18.46 | 2.75% | 3.11% |
| 10 | United States | San Francisco | 15.15 | 1.69% | 2.33% |

***Table 1***: *CO2 emissions in the ten largest OECD metro-regions*

Source: S. Hammer, et al. Cities and Green Growth: A Conceptual Framework. OECD Publishing (2011)

Traffic congestion is one of the most well know effect of urbanization, as well is know the harmful effect on human's health derived by pollutants of vehicle due to combustion engine emission. Indeed, the overburden of pollutants on air and water do not affect only the environmental ecosystems but humans too. Many are the studies presenting the exposure to air pollution as a serious risk for human health. The most severe health effects of air pollution are from exposure to particulate matter and ozone because it is not supplied any safety level for either pollutant. They may even pose a health risk at concentrations below current air quality guidelines [14]. The issue of air quality is a global problem because emissions are local but affect larger scales. Indeed, at traffic or industry hot spots high concentrations of pollutants result from local emissions, however air pollutants, such as ozone, particulate matter and other long-lived pollutants, can be transported over very great distances and frustrate abatement policies at the local scale [15].

Still as far as the natural environment and considering such cities condition of overpopulation and urbanization, parks and green spaces may become scarce and limited in extension. The presence of natural ground areas allows the absorption of run-off, aiding cities water drainage systems. Moreover parks provide a measurable cooling effect and may reduce the impact of the so called "urban heat island". A scientific study about park areas in Addis Ababa, Capital of Ethiopia, confirmed the relative cooling effects of urban parks resulting in significant temperature differences. In particular, the study found the temperature inside green areas cooler of 6-7 °C than the temperature measured in the urban environment [16]. Moreover, benefits provided by natural places are not only related to the environment itself, but parks have also an important psychological effect on city inhabitants, being pleasant and enjoyable places where people may relieve mind from the busy city life.

## 1.2 Society 5.0

In recent years to address human problems arose in cities as a result of population growth and the worldwide phenomena of urbanization, many efforts were invested in improving people's quality life in urban cities. These efforts are driven by advances provided by $4^{TH}$ industrial revolution in the Information and Communication Technologies and for Internet of Things fields. However, as already outlined, the social aspect connected with the growing necessity to guarantee a minimum quality of life for all urban residents, currently increasing in number throughout the Earth, is the main reason for these efforts. As John Wilmoth, Director of UN DESA's Population Division says, for these cities is becoming more and more important follow adequate sustainable management strategies:

*"Managing urban areas has become one of the most important development challenges of the twenty-first century. Our success or failure in building sustainable cities will be a major factor in the success of the post-2015 UN development agenda."* [17]

Hereby, improving all the aspects of living conditions and management in urban environments seems like the crucial element of new emerging cities. These cities, fully integrated with the digital twin technology and based on Society 5.0 principles, are mentioned as smart cities. While the Industry 4.0 is the industrial automatization tendency aimed at redesign working environments, improve the efficiency of industrial processes in terms of productivity and production quality, and develop new business model by means of new technologies such as IoT, big data analytics and other advanced solutions, the Society 5.0 is the evolution of the 4.0 idea. In the evolved scenario, technologies, made available by the $4^{TH}$ industrial revolution, are the tools which make possible improving the quality of people life. The present concept was initially proposed by Keidanren, the Japan Business Federation, and incorporated in the $5^{TH}$ Science and Technology Basic Plan in Japan, as a concept for the future society to which we should aspire. Keidanren federation in its scientific paper refers to Society 5.0 as:

*"Digital technologies and data should be utilized to create a society where people lead diverse lifestyles and pursue happiness in their own ways. In the future, humans will require imagination to change the world and creativity to materialize their ideas. Society 5.0 will be an Imagination Society. The aim is to bring about a society where anyone can create value anytime, anywhere, in security and harmony with nature, and free from various constraints that currently exist."* [18]

The schema presented in *Figure 4*, included within the Policy and Action document about Society 5.0 by Keidanren, on the left shows the different steps of human society throughout the history, while on the right summarizes the factors at the base of the Society 5.0 reportingly briefly advantages that this social evolution is supposed to provide [19]. Thus, the cut of the Keidanren's report shows as main characteristics the social problem-solving skill of the society itself and the ability of creating value anywhere and anytime.

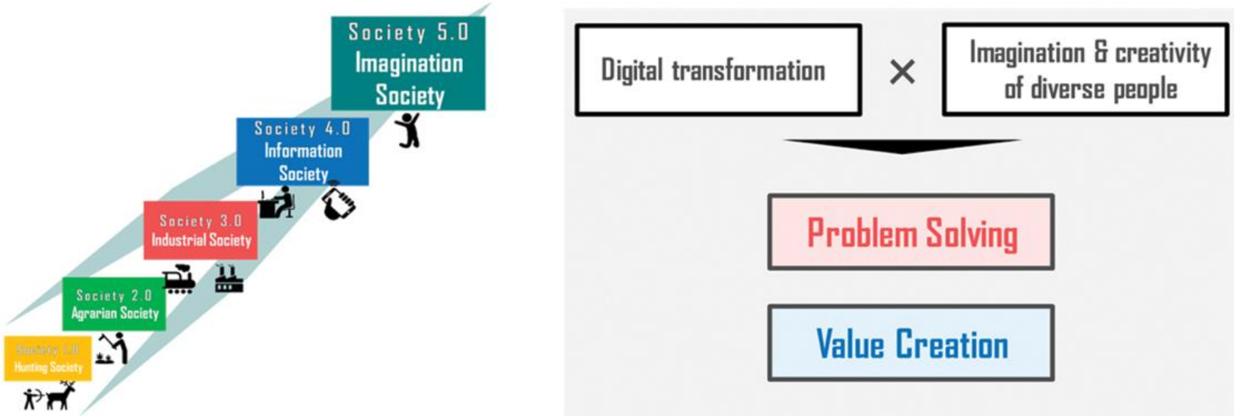



***Figure 4**: Society 5.0*

Source Keidanren: Policy & Action

## 1.3 Thesis objectives

The present thesis aimed at investigating in depth the assigned case study, analysing in detail the various research stages which take part in the set-up of a methodological approach that is clear, complete, and applicable. Moreover, the research promotes an urban development strategy as far as mobility, aiming at improving urban living of Mactan inhabitants according to sustainable development principles.

In detail, the main objective of the study was to investigate the methodological approach behind the implementation of a Digital Twin, supposed to be the tool for the realization of a master plan at urban scale of a pre-defined area in Mactan Island, focusing on the urban mobility system. At the base of the methodology the definition of contents from volumetric and typological point of view which must be included within the Digital Twin for what concern the urban mobility filed of investigation. In brief, the research first aimed at carrying an exhaustive mobility analysis in the area surrounding the international airport of Mactan, located in the archipelago of the Philippines, to then proceed with the design and construction of a smart mobility Hub, that is fully sustainable and integrated with the society and the surrounding environment. Among the others, during thesis development was realized a preliminary understanding analysis of the site of interest, an assessment of common itineraries and path deviations in case of accidental events hindering mobility, the evaluation of endogenous and exogenous factors to understand the potential of the urban system of concern and, at last, was designed the smart mobility infrastructure above mentioned. Having quantitatively and precisely analysed the site, the smart mobility hub was carefully thought to address potentialities and drawbacks find out in the region to finally provide improvements to Mactan citizens quality of life as far as mobility and urban living.

# CHAPTER 2

# STATE OF THE ART

## 2.1 Digital Twin paradigm

Michael Grieves is considered the theorist of the concept. The professor coined the term using it the first time in 2001 during a Product Lifecycle Management course at the University of Michigan. During his talk, referring to Digital Twin he pronounced the well-known general definition still nowadays valid:

"*The concept of a virtual and digital equivalent to a physical product or the Digital Twin.*" [20]

However, before to analyse in detail the definition provided by M. Grieves, just reported above, first must be discussed factors, from social and technological point of view, which have driven to the development of such definition to then have a better understanding of different and complex facets of the concept.

### 2.1.1 DT Background

Currently, the worldwide society is experiencing a digital transformation and digitalization is increasingly becoming a priority for every company to keep pace with changes. Whereby digitalization means, according to the corporation mission and working sector, making use of the various possibilities offered by the correct use of technology to perfect money saving and productivity. The optimization is made possible by the abandonment of traditional analog tools to streamline workflows and automate activities and procedures, whether they are related to production, distribution, marketing and sales, whether they are related to the management of administrative documents and tax material. Furthermore, digitizing also means dematerializing physical places to communicate and share information in real time in a single connected and collaborative environment, even remotely.

Digital twins are revolutionizing industry. Many major companies already use this technology to spot problems and increase process efficiency [21] and, following the actual trend, the half of all corporations might be using them by 2021 [22]. According to Gartner report, Digital Twin was classified as one of the top 10 technological trends with strategic values for years 2017 and 2018, with predictions that billions of things will have their own Digital Twins in the next few years [23] [24].

Digital Twins became trending topic few years ago, but however the concept is older than that since it was theorized in the early 2000s by the professor Grieves. Despite of that, it has only been until few years ago that they started to be affordable. What made this possible were the emerging technologies in the field of information and communication. Such technological improvements came from the industry 4.0 and the corresponding $4^{TH}$ industrial revolution, which were supposed to improve the efficiency of industry by implementing intelligent networking of machines and smart processes together with the help of data communication technology. In detail, among the many innovations provided by Industry 4.0, those which have played a relevant role in the rampant growth of Digital Twins, enabling its implementation at large scale in industry, were the development of the Artificial Intelligence, AI, the Internet of Things, IoT, and the use of complex algorithm and methodologies to analyse big data.

Whereby Artificial Intelligence is meant the intelligence proven by machines, thus the simulation of human intelligence in machines that are programmed to think like humans exhibiting traits

associated with a human mind, such as learning and problem-solving ability. Internet of Things is a neologism which indicates the extension of the internet to the world of objects. On this basis, goods may get intelligence thanks to the ability of sharing own data and access information from other objects connected to the network. Big data refers to a collection of data so extensive in terms of volume and variety that specific analytical technologies and methods are required for the extraction of useful information.
Considering the push of the society toward a digital transformation, the growing necessity to take under constant monitoring any kind of assets throughout the lifecycle, coupled with advances provided by the 4.0 industrial revolution, which have been briefly outlined in the present paragraph, several research fields have shown interest into start investigating Digital Twin uses and potential for answering society problems.

### 2.1.2 DT Conceptualization

Coming back to the definition of Digital Twin given by Michael Grieves [20] and conceptualized within *Figure 5*, it can be assumed Digital Twins containing three different main parts: [25]

- The physical products in real space,
- The virtual products in virtual space,
- The connections of data and information that ties the virtual and real products together.

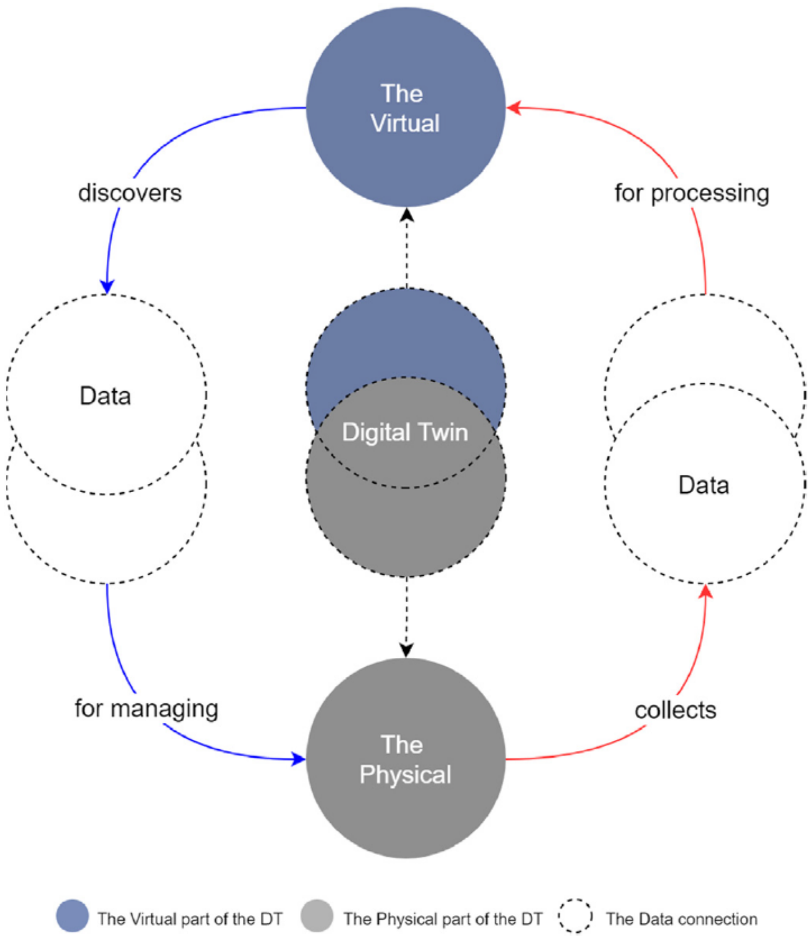



***Figure 5**: The digital Twin paradigm*

Source: C. Boje, et al. Automation in construction 114 (2020)

The loop realizing the connection of the system between the virtual environment and the reality, named "The Physical" within the schema in *Figure 4*, is provided by the great amount of information in many different facets and forms.
Still referring to the idea presented by Michael Grieves [20], the Digital Twin paradigm may be explained as follows. Starting the discussion from the reality, the physical parts are devoted to data collection by using disparate sensors and meters. These data, travelling from the real part of the system toward the virtual model, are raw data which require data processing algorithm. On the other hand, "The Virtual" counterpart of the reality discovers data, already affected by several transformations, which are then reflected to the physical part through actuators for the asset management operations in the real World. Thus, it can be assumed the virtual part being the most important one. Indeed, in a simpler way, the physical part collects real world data and sends them to the virtual part for processing. In return, the virtual model applies its imbedded AI-based engineering models of machine learning to discover information which are then used for managing the day-to-day usage of the physical asset. Accordingly, taking into account the observations made within paragraph *2.1.1 DT Background*, it is clear that an important contribution to Digital Twin development came from innovations within the field of information and communication technology got with the Industry 4.0. Indeed AI, IoT, big data analytical methods, machine learning and sensors are feeding information in near real-time giving life to these digital models which, in time, have evolved becoming more complex than their real and physical counterparts, as they no longer represent single isolated objects but network of interconnected things.
According to Michael Grieves theory, the Digital Twin capability supports three of the most powerful tools in the human knowledge tool kit. These three tools are: conceptualization, comparison, and collaboration [20]. Are now treated one by one these three tools, highlighting differences between human abilities and machine approach and focusing on the advantages that the implementation of a Digital Twin may provide within the organization of a company.
Talking about conceptualization, we may say that humans do not process information in the same way that machines do. During conceptualization performed by human's mind, a large amount of information is lost. Indeed, we tend to automatically process and re-arrange the information acquired by our eyes. The Digital Twin offers the possibility to directly see the final result of the mental process, thus eliminating all steps of translation and processing which reduce the level of detail. The example provided by the professor M. Grieves within his report to better clarify this concept is the following: "*instead of looking at a report of factory performance and re-conceptualizing how the product is moving through the individual stations, looking at digital twin simulations allows us to see the progress of the physical product as it is moving and actually see information about the characteristics of the physical product"* [20]. In terms of comparison tool, having the real and the virtual product physically separated the comparison that results is inefficient. On the contrary, with the Digital Twin model it is possible to choose the parameter of the real product that we want to evaluate through the virtual model, fix the ideal measurement and finally visualize the tolerance corridor. Moreover, parameters may be adjusted to intervene directly on the product performances and tolerance. At last, the collaboration among humans. People collaborating can bring more intelligence, increase the work productivity, widen analysis perspectives, and achieve better problem-solving abilities. With a Digital Twin that skill is even more emphasized. That is one of the main advantages provided by this technology. A shared conceptualization that can be accessed in exactly the same way by an unlimited number of individuals who do not need to physically stay in the same place viewing the same dashboard [20].

To realize a Digital Twin capable to accomplish the functionalities described for each human knowledge tool, a well-designed model should ideally include all the information characterizing the physical object in the reality. In detail, the product should be carefully described through a 3D representation of its aspects at the mechanical, geometric, and electronic level. Moreover, the digital model should be enriched by embedded software, product data and data collected by pervasive sensors and meters monitoring it continuously. Having the model built and running to acquire information, it is possible to exploit the benefits given by this technology for different purposes:

- Simulation purposes: for the design of a new product, Digital Twin can be used for quick and inexpensive prototyping of new ideas, particularly from the standpoint of user experience. For instance, Digital twin models of transport hubs may have a positive impact on the transport network infrastructure increasing the system efficiency and finally resulting into a better travel experience for passengers.
- Operational performance: By continuously monitoring operations, processes and systems it may be predicted in advance anomalous behaviour, risks and errors, allowing workers to react promptly and reduce downtime. They can also apply machine learning for predictive maintenance. For instance, into a sewer system can be identified a blockage along the system by using anomaly detection algorithms and accordingly react to manage such kind of problem or any other.
- Live data management: Digital Twin can help with the management and the maintenance of assets by taking trace of records of inventory, processes, historical and inspection data. This capability is useful for asset manager, real estate owners and maintenance teams to identify inefficiencies of assets management and possible strategical ways to address and solve them.
- Supply and Demand: it is possible to aim to an entire transparent supply chain by tracking inventory in real-time and suggesting or automatizing the rearrangement of the supply chain according to demand. Models of ridesharing network is an example. Indeed, by knowing in real time the demand it is possible to redistribute drivers accordingly, in such a way to perfect travel paths and the efficiency and efficacy of the entire ridesharing service.

At last, summarizing, is possible to define Digital Twin technology as an evolved management model of a process, system, product or even service. The association between physical reality and virtual reality makes it possible to analyse the large amount of data provided by sensors and meters installed on the system. As a result of such investigations, companies are able to apply systems monitoring such that it is possible to reason in predictive mode, addressing problems even before they occur in the reality, so to optimize operations and increase efficiency of any process. Moreover, by using proper simulation software it is possible to develop new opportunities, planning future businesses with less risk and a greater return on investment. Finally, Digital Twin technology helps companies improve the customer experience by better understanding specific needs of clients depending on the case. Consequentially, existing products, systems and services may undergo specific improvements to address any kind of request may be presented.

### 2.1.3 Fields of application

Having introduced from a general perspective the concept of Digital Twin, may be now outlined opportunities provided by its implementation in different industry sectors. The application of Digital Twin technology may vary in scale and complexity depending on the working field of concern and the final goal of its implementation. What is clear is that, through the integration with internet-related technologies, viewed within paragraph *2.1.1 DT Background,* the Digital Twin is potentially applicable for many different industry sectors.

In *Figure 6* different application fields of Digital Twin are shown. [26] Industry sectors of concern include aerospace, healthcare, city, construction, manufacturing, vessel, drilling platform, electricity, agriculture, automobile, and many other important industry sectors. In the same figure the architecture of a Digital Twin is schematized. As already explained in sub sub-chapter *2.1.2 "DT conceptualization"* the architecture of this technology includes the physical part in the reality, the virtual 3D model and the set of data realizing the connection among the entire system [26].

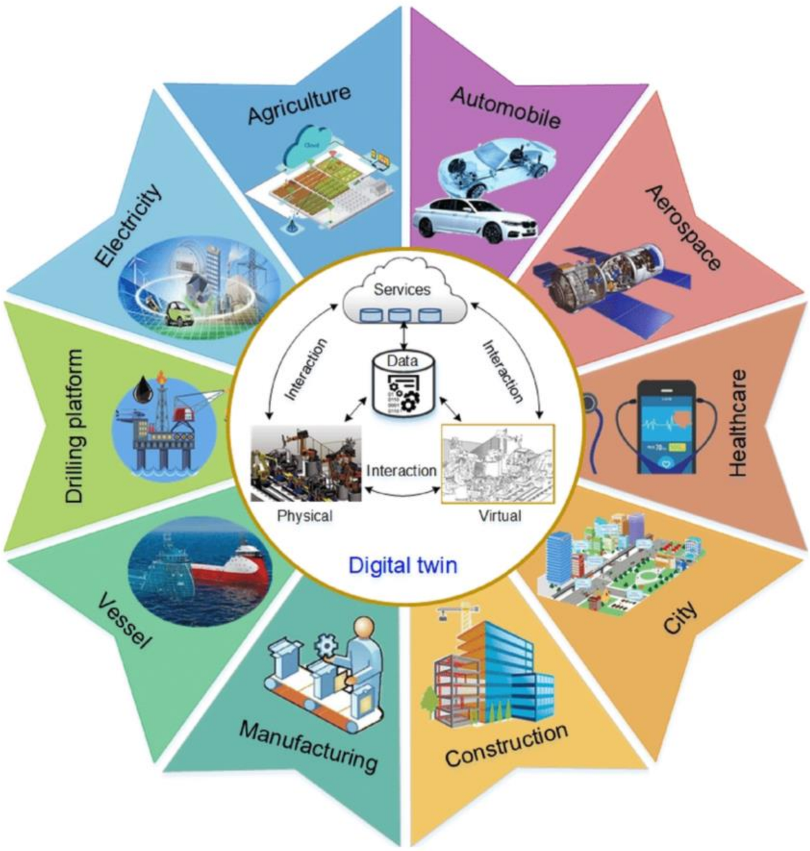



***Figure 6:*** *Different application fields of digital twin*

Source: Q. qi, et al. Journal of Manufacturing Systems

Follows a brief description of some successful case study of implementation by worldwide leader companies in various industry sectors, from manufacturing to healthcare industry. Digital Twin application for cities is a topic which will be treated separately within sub-chapter *2.3. "Smart City"*.

In manufacturing Siemens is using Digital Twin in production planning to capture, analyze and act on operational data for the efficient design of new products [27]. ATOM is the Digital Twin of Siemens developed to emulates the global maintenance operations of Siemens turbine [28].

CNH Industrial, a global leader in production and selling of agricultural, industrial, and commercial vehicles, decided to test the Digital Twin technology for evaluating and selecting different maintenance policies in various scenarios. The company worked with a simulation software provider, AnyLogic, on a pilot project related to the manufacturing line dealing with Iveco Daily van chassis welding [29].
In the software development field, companies, such as SAP, Microsoft and many others, are promoting the use of Digital Twin technology. From their website is explained how, thanks to the implementation of machine learning and the Internet of Things solutions, is possible to gain insights to help companies perfect operations and costs, innovate products, and deliver new services answering specific request of clients [30] [31].
In the health care sector, GE Healthcare is thinking to the hospital of the future. It is supposed to be a digital safe environment to test changes in system performance and to help leaders design and execute models of care which are revolutionary for patients, families, and caregivers [32]. Siemens is using Digital Twins to replicate human physiology. Virtual planning is used to visualize responses to treatment before the intervention. Siemens Healthineers is developing algorithms capable to generate digital models of organs based on a vast amount of data [33]. Also Philips, the medical device maker, is working in this direction. In 2015 it has launched the Philips Heart Model, that is a clinical application which represents the first step toward the realization of a Digital Twin of human heart [34].
Considering the energy sector, the Digital Twin technology is being exploited because it allows to visualize big and complex assets often in remote ocean locations. As an example, in the offshore oil and gas sector, the company Aker BP used Siemens's analytics technology in its Ivar Aasen project off the Norwegian coast. The implementation of such technology in this case has reduced the workforce requirements on the platform and has perfected equipment maintenance schedules [35]. Finnish electricity transmission system operator, Fingrid, worked with IBM, Siemens, and many other partners to build a Digital Twin of the actual Finland's power network. The Digital Twin of the power network is used in day-to-day grid operations, helping staff to manage power flows and protection settings, to meet demand without overloading transformers or transmission lines [35].
For what concern infrastructures, the transportation global leader Alstom has built a Digital Twin by using the AnyLogic simulation environment. The Digital Twin was realized to enhance the management and maintenance operations on Alstom's train fleet operating on the West Coast Main Line, one of Britain's busiest inter-city rail routes. Alstom's Digital Twin includes details of every train in the fleet together with operating timetables, maintenance regimes, and also information about the available capacity of each and every maintenance depots of Alstom company. Since the platform is connected in near real-time with trains location and planned travels, the scheduled maintenance operations can be continuously adapted to address firstly most urgent activities [36].
In the construction industry, the investment in technology is speeding up the digital transformation. As reported by M. Stych, the Director of Arup London, within the 2019 report on Digital Twin, what must be well known is that, "*in property market success in any use case relies on being able to integrate data from te various interested parties, builders, owners, managers, to enable effectively analysis and avoid rebuilding basic requirements each time*" [37]. Arup Amsterdam is building a Digital Twin of the Dutch government's County Hall building in The Hauge. The aim of the present project is to achieve by 2040 that all buildings in the province are energy neutral [38]. In this case the approach is twice, on one side the project

aims to optimise the current functioning of the building and on the other side it renovates, uplifts and transitions the building where needed.
The Digital Twin technology may be successfully implemented also in consumer and retail sector and in the emerging e-commerce. In the consumer products sector, the value of Digital Twin may have different sides. On one side companies are investigating the development of such technology to have a model tracking the flow of products through supply chains. On the other side they are also interested in systems that can extract valuable details from large dataset produced by large number of comparatively simple models. In retail and e-commerce activities, companies used to exploit data on past purchases, web browsing habits and social media activity to target advertising and promotions for specific customers and contexts. With the implementation of Digital Twins, this model may turn into sophisticated consumer Digital Twin which ideally should be able to predict future trends and consumer behaviours and proactively influence purchase decisions [35].
In the logistic sector, digital twins have not yet achieved widespread application. At DHL, an international courier service, as it is reported within the DHL trend research document about the impact of Digital Twins on the logistic industry, they are starting to think about a twin which "*would be a model of an entire supply chain network*" [35]. The visionary Digital Twin thought by DHL company is presented in *Figure 7* [35]. Company's idea is to create a Digital Twin of each factor involved in the logistic chain network, including the model of packaging and container, means of transport delivering goods such as vessel, train, delivery van and truck, shipments, warehouse up to the model of the global logistic infrastructure. Such all-encompassing twin would include not just logistic assets but also oceans, railways lines, highways, streets, customer homes and workplaces [35].


***Figure** 7: Digital Twin in logistics*

Source: K. Dohrmann, et al. Digital Twins in Logistics, DHL

## 2.2 Urban DT

Chapter 1 of the present thesis paper was focused on the presentation of themes related to the Earth's overpopulation and the consequent phenomena of urbanization and megacities growth. Considering the rapid development that urban areas of the globe are experiencing, designing and managing cities of the $21^{ST}$ century is becoming increasingly a complicated matter for urban planners and policymakers. Indeed, the growth of cities does not involve only larger boundaries, which spread out including suburb areas, but it also involves the increase of population, people tend to aggregate in the same limited areas, the growth of energy requirements and energy consumptions, growing steadily with the presence of people living and working in the city, and finally the rise in demand of infrastructures and services such as transport, energy, health and housing. As a support of this need, John Wilmoth, Director of UN DESA's Population Division, says *"Managing urban areas has become one of the most important development challenges of the twenty-first century. Our success or failure in building sustainable cities will be a major factor in the success of the post-2015 UN development agenda."* [39]

In this global scenario, to respond to the growing need of having an efficient, evolved and adequate management model of the city environments of the future, the concept of Digital Twin was introduced. The original paradigm was extended to the realm of smart cities as the 3D replica of a city connected to the internet of things. Such models are gradually becoming fundamental tools to visualize the pulse of the city in near real-time with layered data. Sensors distributed across the city record information on public buildings and urban infrastructure, environment and climate conditions, energy consumption, flows of people and vehicles and any other kind. The promise of a city Digital Twin is to use this large amount of information from the real environment to provide decision makers of a reliable simulation environment to test policy and evaluate spatial solution with the double aim of enhancing city resilience and improving people quality of life. To this latter purpose, an urban Digital Twin ideally aims to develop new opportunities improving the engagement of citizens and communities which then must live the designed urban environment [40]. Indeed, this technology not only helps to enhance existing urban systems, but it allows citizens to be co-author and take part in city redesigning process. Given that the 32% of the world's population lives in informal settlements, as indicated by Sarveen Chaudhary, the Urban Development Minister in the state of Himachal Pradesh in India, during her intervention in the Smart City Expo World Congress 2019, Digital Twin can be an excellent inclusion tool for the most disadvantaged groups, permitting the empowerment of local communities [41]. A possible solution to integrate knowledge by citizens about the built environment, for the realization of the 3D virtual model, is to collect data via open maps using tools such as Open Street Map, which was already tested in these terms for other purposes. However, what really can empower citizens and make them co-producers of urban systems and services, is the submission via intuitive video games platforms of their own proposals regarded the urban environment redesign process. Pontus Westerberg, member of the UN-Habitat Global Space Programme, outlined the use of videogames during his intervention in the Smart City Expo World Congress 2019. As it was explained by Westerberg, the project considered the use of a popular computer game, Minecraft, whom interface was used by cities inhabitants to graphically realize a proposal of urban space design and directly submit the developed ideas to authorities in charge for the redesigning process. Then, by means of mixed reality tools, authorities had the possibility to superimpose the virtual space by Minecraft on the real environment and visualize the application on the platform to finally compare differences and solve urban spatial problems.

The standard definition of Digital Twin, as it pertains to the AEC industry, is widely accepted today: *Digital Twins are virtual replicas of physical building assets connected to the data in and around them and deliver unique value at different phases across the entire lifecycle from design through demolition* [40]. In a more simplistic way, Digital Twin technology implemented at urban scale allows to test and understand how the urban environment is supposed to be realized will behave in a wide variety of environments, using virtual space and simulation. Different technologies combined are related to a single database which contains all the design data of the city, simulation software and real-time data collected by various devices installed all around the environment. At last, the possibility to access data easily and from many different sources in a single centralized, synchronized and shared platform acting as a digital environment for urban operations planning.

### 2.2.1 Examples of Urban Digital Twin implementation

Digital Twins have the potential to help deliver on many of the great challenges the world is facing today, including urbanisation, population growth, global warming, pollution, escalating infrastructure costs, and sustainable development planning. This is the reason why within Gartner report, as already hinted in sub sub-chapter *2.1.1 DT Background*, Digital Twins are classified as one of the top 10 technological trends with strategic values for years 2017 and 2018 [23] [24]. Due to greater potentialities offered and the positive feedback from experts, the number of urban Digital Twin implementations is increasing across the World. As it was correctly stated by Neil Thompson, Director digital construction at Atkins, interviewed by M. Jansen "*The Digital Twin is about being able to place information into the right hands of the right people at the right time*" [40].
Within the present paragraph are presented some examples of several cities across different continents in which this technology was successfully implemented to start addressing various global issues among those mentioned.

*Amaravathi:*
In the Indian state of Andhra Pradesh will be built the smart city greenfield of Amaravathi, the first entirely new city to ever be born as a Digital Twin. Michael Jansen, Chairman and CEO of Cityzenith, the company supplier of the software platform for the 3D prototype of Amaravathi says: *"Everything that happens in Amaravati will be scenarioized in advance, to optimize outcomes, and adjust on the fly to keep pace with change."* [40] The platform supporting the Digital Twin will be customized to allow government agencies, commercial businesses, and citizens to use a single platform for a wide range of purposes, including among the others [42]:

- real-time construction progress monitoring,
- environmental monitoring,
- advanced mobility and traffic monitoring and simulations,
- advanced microclimate and climate change monitoring and simulations,
- digital "drag and drop" building permit sub-mission,
- digital statutory compliance-related preliminary analysis.

One of the most innovative function of the present Digital Twin concerns the possibility for each citizen of Amaravathi to have a user ID to easily enter the platform. In this way the Digital Twin turn into an open portal in which citizens may get all government information, notifications, forms, and applications they need.

*Hong Kong*:
In China, the special administrative region of Hong Kong is being entirely digitalized by Arup firm. The company is realizing an urban scale Digital Twin platform, called Neuron City, to map the space, people, and activities in the real city environment to a virtual Hong Kong. Neuron City, which incorporates GIS, BIM, IoT, cloud computing and AI technology, is supposed to solve real complex problems of the urban lifecycle by integrating different city systems from transportation to security. The first stage of Neuron City, which was completed in 2018/19, consists by a city-scale information model platform operating system which include the following capabilities [43]:

- 3D modelling and spatial analysis
- Visualisation of simulation data and statistics
- Building data dashboard
- Parametric design module
- Real-time data visualisation and analysis

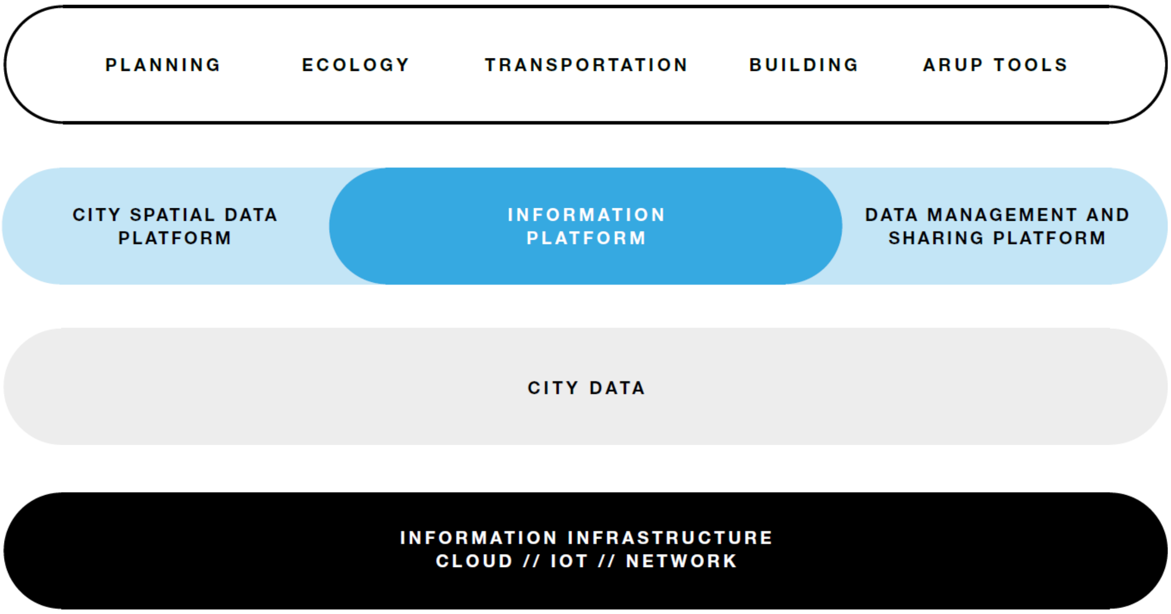



***Figure 8**: A holistic view of the Neuron City prototype*

Source: Digital Twin Report. Arup (2019)

Reading the Arup report on Digital Twin [43], the first-stage platform adds value by integrating data from different sources for collaboration and by developing innovative city prediction and control applications for decision-making process. One of possible usages of the platform may be captured in the following example. Online house price data were grouped within the platform database and mapped by location on the dashboard of Neuron City. This map was useful to provide a quantitative basis for planning into real estate market. Future strategies of Neuron City platform include, among the other, developing partnership and collaborating with suppliers to continue solving urban problems and make improvement to people quality of life.

*Singapore:*
Virtual Singapore is the World's first city-scale Digital Twin and it was developed by different government agencies exploiting the software platform from the French firm Dassault Systèmes [44]. The Digital Twin is based on IoT sensors, big data and cloud computing combined with 3D

models, GIS and BIM datasets. Basically, Virtual Singapore offers a collaborative platform which can be used by urban planners to simulate the testing of solutions in a virtual environment. These tests aim to show how a single change could affect the lives of millions of people and the systems they depend upon, and consequentially tests are supposed to help make long-term decision on fields such as infrastructure, urban planning and resource management. As it is reported by the digital government office of Singapore website, the main capabilities of Virtual Singapore platform are the following [45]:

- Virtual Experimentation
- Virtual Test-bedding
- Planning and Decision-Making
- Research and Development.

Although Singapore is considered the most technological advanced Country in the World, Thomas Pramotedham, CEO of Esri Singapore, believes that Digital Twin should become a priority for any city involved in the digital transformation. According to Pramotedham, "*only with a digital twin in place, can government agencies effectively analyse what can be done with the data and improve citizen living, create economic opportunity and revitalize a closer community.*" [46]

***Figure 9**: Virtual Singapore*

Source: www.smartcitylab.com. Singapore experiments with its digital twin to improve city life. (2019)

*Cambridge:*
The Ove Arup Foundation established in 2018 a four-year research project entitled '*Digital Cities for Change'*. The project is focused on the relationship between city managers, engineers and urban designers, specifically in the global scenario of digitization which is concerning the planning, functioning and management of cities of the future. The research aims to cement the acquired knowledge concerning smart cities and infrastructures to advance in research and finally identify the new skills needed for future design and construction challenges [47]. In this scenario, the Cambridge Centre for Smart Infrastructure and Construction, supported by the Ove Arup Foundation in collaboration with local authorities, is currently developing a Digital Twin pilot for the Cambridge sub-region. The Cambridge Digital Twin pilot project will test the future of commuting workers of Cambridge investigating policies, deeply permeated by the use of digital technologies, to realize improvements for the urban area. In detail, isolated policies from transport, housing, environment and energy will be bridged togheter within the virtual environment to quantify some of the interdependencies among transport, air quality, housing, energy and infrastructure, which may be exploited to the reduce traffic congestion and improve town air quality. At this stage the Digital Twin just includes recent trends of journey to work in Cambridge and considers differences in terms of people ages, employment status and external

factors affecting daily travel. Moreover, will hypothesised future journeys based on different transport investment, housing development policies, new technologies and flexible working condition [48].

*Helsinki:*
In Finland in 2018 was launched the Kalasatama Digital Twins Project. The general objective of the project was to produce high quality Digital Twin city models of the Kalasatama area and to share the models as open data to all operators. The model is produced with a CityGML standard-based semantic city information model and a reality mesh model and serves as a platform for designing, testing, applying and servicing the entire lifecycle of the built environment, as well as for smart urban development. The project team hopes that these city model platforms will promote diverse product development, research, teaching and innovation [49].

*New South Wales:*
The Government of New South Wales, Australia, is creating an open-source interactive platform on which capture and display real-time 3D and 4D data on the urban environment [50]. The project, which enlists the help of Department of Finance, Services and Innovation's Spatial Services and the Commonwealth Scientific Industry Research Organisation's Data61, aims to stimulate development actions in the entire state. The Digital Twin will assist better planning, design and modelling for NSW's future needs. The project has already demonstrated the ability to upgrade NSW's spatial data to 3D and 4D, with integration of live transport feeds and infrastructure building models. Moreover, even if it is still at primordial state, it has also demonstrated to provide benefits at national and local government levels, from disaster management to bus schedules [51].

In conclusion, although for the time being there are just few cases where the Digital Twin concept is applied in the urban environment, it will have a rampant growth in the next future. The global technology market advisory firm ABI Research, as it is reported on its website, a company devoted to provide strategic guidance on the transformative technologies that are reshaping industries and economies across the world, has predicted actual deployments of Digital Twins at urban scale growing from just a handful of early applications in 2019 to more than 500 by 2025 [52].

## 2.3 Smart City

At this stage of the present thesis paper, what clearly comes up from the discussion is the great spreading that Digital Twin technology is experiencing. Indeed, even if the theorized idea was originally developed in the industrial field for manufacturing, the concept is now embracing different and disparate fields of application, in particular it is spreading toward the smart city environments. As it was shown with the above described few cases of urban implementation across the World, the Digital Twin concept and the urban modelling paradigm, are transforming how cities are designed, monitored, and managed under all aspects of concern, from transport to energy.
Before to define a smart city, a relevant distinction must be discussed. When argue about smart is important to not make confusion with automatization concept. A city into which electronic devices are just devoted to collect information from the surrounding environment but then are the authorities in charge for city management to remotely control urban systems, is an

automatized city and cannot being defined as intelligent. In this case the smarter part is left to people devoted to the management of urban environment which, according to parameters made available by hardware technological devices, act to satisfy needs of the society. A city may be defined smart if it directly initiates decisions itself by learning from citizens' habits, with the purpose of making use of the AI to bring improvements to people quality of the life. In such a case, data collected hardware components are evaluated by means of AI-based software and accordingly urban systems are automatically managed by the city software itself activating actuators. The right definition of smart, in this case smart building, is given by Michael C. Mozer professor at Department of Computer Science and Institute of Cognitive Science of the University of Colorado. The professor within his project book, Smart Environments: Technologies, Protocols, and Applications, about smart buildings wrote: *"Instead of being programmed to perform certain actions, the house essentially programs itself by monitoring the environment and sensing actions performed by the inhabitants (e.g., turning lights on and off, adjusting the thermostat), observing the occupancy and behaviour patterns of the inhabitants, and learning to predict future states of the house [...]"* [53]. The definition is given in terms of smart building, however, from a general perspective, it is valid for anything considered smart, thus cities too.

In summary, what distinguish a smart city solution from a not intelligent environment is the combination of three different factors, the hardware components, AI-based software and a communication network. The hardware components may be further distinguished into two. Sensors and meters are installed across the city to make the environment itself capable to recognize what's happening within the urban area. A sort of human senses to determine and collect parameters related to the urban environment which, for instance, may be useful to understand the stability condition of an infrastructure, to measure the wind intensity or even to detect a gas leak or to register the carbon dioxide level in the downtown. On the other hand, electronic actuators are devoted to change the state of different urban systems by controlling the engine of engineering technology. Since hardware devices supply only raw information, the need is to develop some software, based on artificial intelligence, to manage the technology of hardware components such as sensors and actuators. This software by means of advanced big data analytics methods and machine learning algorithms is capable respectively to extract information from the whole dataset of acquired data and learn from the city life cycle. The knowledge acquired are then exploited to propose solution and even to predict future states of the environment. At last, to allow the city to act as a whole, is required a communication network. The network represents the nervous system of the city because it serves to connect all devices between each other and with the artificial intelligent component, that is the software.

Exist several smart city definitions that are used today in literature to describe this concept. Angelidou defines smart cities those urban settlements which make a conscious effort to capitalize on the new ICT landscape in a strategic way, seeking to achieve prosperity, effectiveness and competitiveness on multiple socio-economic levels [54]. Lazaroiu and Roscia discuss that the smart city is a community of average technology size, interconnected and sustainable, comfortable, attractive and secure [55]. Picon argues that smart city can be seen as a city whose digital tools allow the optimization of its functioning and sustainability, as well as of its inhabitants' quality of life and the types of relationship they can maintain with one another [56]. European Commission takes a bit more system-oriented approach defining the smart city as pioneer measures in areas of buildings, energy networks and transport [57].

Summarizing is possible to define smart city as a hyper-connected environment, technologically equipped to improve the lives of their residents. In practice, that translates into a public platform where all kind of city information can be transparently shared among local authorities, citizens and entrepreneurs in order to realize and manage an urban environment that adapts dynamically for needs of the modern society. Pillars of a functioning smart city are the following four, economy, government, environment, and mobility. However, a great aspect of concern remains the collection and the free access of large datasets and the cooperation among these pillars, which is made possible by the implementation of technologies such as IoT and big data analytics. In *Figure 10* is summarized the idea of hyper connected environment. In detail, are shown some characteristic components of a smart city belonging to the abovementioned pillars, from smart economy to smart mobility, and moreover, is highlighted the required connection to the world of internet and the availability of big data to network the city.


***Figure 10**: Smart City components*

Source: www.thestorypedia.com. The third list of smart cities.

Of course, the realization of a project concerning a smart city is not a trivial matter. Indeed, into the design phase the most common obstacle encountered is the diversity of stakeholders involved and consequentially the increasing necessity to make possible the realization of an effective collaboration and flow of information among their different fields of knowledge. In other words, must be taken into account simultaneously, and then merged together, needs and requirements from government, local authorities, citizens, engineers, urban designers, companies, and other parts of different sectors playing whatever role in the design, realization or management processes of the urban area involved within the research. That is of course a priority if the designed smart city is intended to be the solution conceived to address urban issues of concern. As a result of that, as it occurs for any large and complex project, to achieve the predefined goals of the intended construction of a smart city, stakeholders for the urban planning process consider the use of a purposely conceived strategic tool, that is the master plan.

## 2.4 Master Plan and Urban Planning

A Masterplan is a strategic document which implements territorial development programs by developing an overall hypothesis on the planning of an area, including the identification of the stakeholders, the possible sources of financing, the tools and actions necessary to define the future urban planning of a territory. It therefore defines a set of actions that are coherent in it, and which allow first the development of territorial planning projects and then urban planning. In this process, it is a representation of the strategic guidelines for the future, defining in broad terms the sequence of the achievement of the main objectives over time. The validity of its content is related to the economic and social purposes for the citizens of the territories affected by the territorial planning project. However, its effectiveness is determined by a process of participatory democracy supported by adequate communication tools that use simple and direct language capable of addressing a large and heterogeneous number of subjects.

### 2.4.1 Master Plan implementation

The concept of Master plan was just presented and defined as a first vision of a long-term project in program, serving as dynamic support into which are defined, step by step, all aspect pursued during the study development. On such basis, the implementation of a Master plan is divided into three major steps:

- Analytical-Interpretative phase,
- Design phase,
- Management phase.

Phases of concern in the development of an efficient Master plan are now treated briefly:
Having preliminary identified a specific and limited area of investigation, the first phase of a master plan organization aims at evaluating all issues of concern affecting the territorial context under investigation. In detail, the analytical-interpretative phase aims to highlight and describe clearly the state of the places of the territory under investigation in terms of criticalities, for which take provisions, and in terms of potentialities, on which leverage to develop opportunities. With particular attention in order to construct a deeper understanding framework of the area, are analysed the economic activities present and the social context of the area. Statistics about population are significant in terms of growth rate, poverty rate and other insight about local community. At last, matter of concern of the first phase is the historical cultural heritage, including religion habits and traditions, and last the environment in terms of physical characteristics of the territory in which the project must be inserted in harmony respecting all constraints of the natural world.
During the development of the second phase, are defined the strategic development axes of the research. In other words, in this phase are described the strategies, in terms of actions, aimed at enhancing the economic system and the cultural, social, environmental and landscape heritage of the considered area. The management phase is a complex process with monitoring and feedback actions which integrates urban planning tools with advanced financial programs.

### 2.4.2 Urban Planning

Urban planning is about designing towns and cities which, regardless of whether they are smart or not, function effectively and meet the needs of people living in them. This technical process is moreover concerned with bringing benefits to people, controlling the use of land and enriching the natural environment. It requires careful assessment and planning so that community needs, which start get missing in very dense cities due to population growth and urbanization, such as housing, environmental protection, health care and infrastructure access can be addressed properly. Urban Planning means manage urban development in order to prevent the uncontrolled and haphazard construction, especially in central urban areas where unplanned development

gives rise to densely populated areas characterized by the lack of supporting infrastructure and services. These inadequate services may include, among the others, transportation facilities, sanitation systems and solid waste management, health care services, water supply and education infrastructures. These services are all essential for the effective functioning of an urban environment, indeed, from the ancient they should be always available for people.
There is evidence of urban planning and designed communities dating back to Mesopotamian, Indus Valley, Minoan, and Egyptian civilizations of the third millennium B.C. Archaeologists studying the ruins of cities in these areas find cobbled streets arranged at right angles in a grid pattern. The idea of a planned urban area evolved when several civilizations starting with the Greeks adopted it. The ancient Romans, inspired by the Greeks, built their cities on orthogonal plans for military defence and public utility. The spread of the Roman Empire popularized urban planning ideas, but after its decline these ideas slowly disappeared. Entering the modern era, the concept of urban planning arose in Europe just in the 19th century. Basically, it emerged from the awareness that public health and infectious disease outbreaks were closely related to inadequate housing and poor sanitation. By the $20^{TH}$ century the idea of land-use zoning was the dominant approach to urban planning. Whereby zoning is meant the creation of defined areas within a town designated for different activities such as residential, commerce, industry, etc. The aim was to improve urban living conditions by separating people from noxious land uses. However, zoning also had the effect of creating a social divide by separating areas where well-off people lived from those occupied by people with little or no income, and so increase inequality between services and facilities available in different zones. Moreover, in $19^{TH}$ century the issues of working-class districts within industrialized cities, that grew at an incredible rate, were becoming increasingly evident as a matter of public concern. Recommended urban planning practice has since moved away from the zoning approach and currently adopts principles of integrated usages which are supposed to ensure the sustainability of future towns and cities.

### 2.4.3 Sustainable planning pillars

Sustainability can be described as the ability of self-maintenance and self-generation of an ecosystem. In the urban planning field, the present capability is typically expressed by three different dimensions harmoniously integrated between each other: economy, society and environment. In brief, the principle of the modern concept of urban planning is to manage land use so that it is sustainable. Accordingly, urban planning should bring economic benefits with social equity and without causing environmental harm. The promotion of "*socially and environmentally sustainable human settlements development*" [58] is part of the mission of UN-Habitat. As it can be read from the official website, the vision of the present programme is to promote "*a better quality of life for all in an urbanizing world"* [58]. The UN-Habitat approach to urban planning, as far as the society dimension, is based on the realization of sustainable neighbourhoods and cities which should be compact, integrated and connected. The five principles summarized in the following bullet list support the sustainable idea of neighbourhoods proposed by the UN-Habitat vision:

- Adequate space for streets and an efficient street network,
- High density of people: at least 15,000 people per $km^2$,
- Mixed land use: housing mixed with business and other economic uses,

- Social mix: houses in different price ranges and tenures (rented, owned etc.) in any given area,
- Limited land-use specialisation: large areas should not be allocated for a single function.

In contrast with the zoning approach, these five principles emphasise the need for mixed land use developments integrating different functions of residential, commercial and business together. Ideally, urban plans should mix housing with employment opportunities and include schools, shops and health care facilities. An adequate street network will allow access for cars, public transport and service. Plans should also consider the need for places of worship as well as for entertainment and leisure. Incorporating this diverse range of requirements for the urban environment is challenging. To be successful and sustainable urban plans should ideally be developed with the participation of the people who will be living and working in the area. Meeting these expectations also requires significant economic resources, an effective decision-making and regulatory framework, and good governance.

# CHAPTER 3

# METHODOLOGY

Chapter 1 of present paper described in detail the problem of population growth and urbanization the world is experiencing. In the same Chapter a possible solution which humanity has found to fight this global issue was briefly introduced. Chapter 2 was spent to deeper the understanding on the suggested solution, analysing the state of the art as far as Digital Twin and Smart City. Chapter 3 is devoted to the development of the research, as from thesis title, a methodological "Urban-scale Digital Twin for a master plan in the area adjacent to Cebù Airport, Philippines".
A though premise is to highlight the multidisciplinary nature of the research which merges civil engineering study course and automotive engineering study course. Despite the multifaceted nature of the research, in the present thesis are described tasks from the civil-building engineering point of view performed to obtain the final unique result which derives by the collaboration and integration of competences from the abovementioned different backgrounds. However, before start developing the research under investigation, in sub-chapter 3.1 is briefly explained the methodology and the workflow followed during thesis development, whereby methodology means the different steps which have been pursued to achieve the final result presented as outcome of the present study project.

## 3.1 Methodology & Workflow

Respecting the multidisciplinary approach followed in developing the research, it is now presented the methodology of the study and it is then introduced more in detail the workflow followed to address tasks related to civil engineering branch of the research.
As preliminary stage in order to have a deeper case study understanding, civil tasks focused on the collection and analysis, by GIS-based software, of spatial data concerning site population density, network limitations and traffic zones accessibility. Moreover, to have a clearer understanding of spaces *Arc-Scene* application was used to realize a 3D mass model of the area which then allowed to know the actual urban organization of the research area. Simultaneously, automotive engineering students focused onto the realization of a macroscopic data analysis on traffic by using *TransCAD* software. Once main potentialities and drawbacks of the site were understood by both study branch, it was implemented the SWOT strategic planning tool. As a consequence of that and because of an internal decision-making process the attention was shifted on urban mobility, in detail on two mobility-related aspects that are traffic congestion and $CO_2$ reduction. From now on the passages for the development of the proposed idea of mobility Hub. Hereby, as a result of outcomes by macroscopic simulations, accessibility analysis and solar aspect analysis, the latter realized on *ArcMap* software, it was selected the intervention area. Then, automotive investigation focused on traffic microscopic simulation at the selected intersection, realized by *Vissim* application, and the related emission analysis by *Moves* software. On the other hand, civil effort was focused on the set-up of a BIM model in *Revit* then exported as *FBX* file in *3DS MAX*. Outcomes derived by just cited tasks served as main inputs to the realization of the interactive scene. The scene also shows the surrounding urban area, however realized in *3DS MAX* with a lower level of detail with respect *Revit* parametric model, and moving vehicles, which actually were built in *Sketchup* and then exported as well as other objects of less importance. Following, the software *Unity* was used to realize the connection between the simulation environment and the urban model to finally get the interactive scene. At

last, civil investigation was focused on Hub energy requirements and technical knowledge about implemented solution of urban micro-mobility, while automotive efforts were focused to deeper the knowledge about VR technology and improve scene interactive model using Oculus devices.

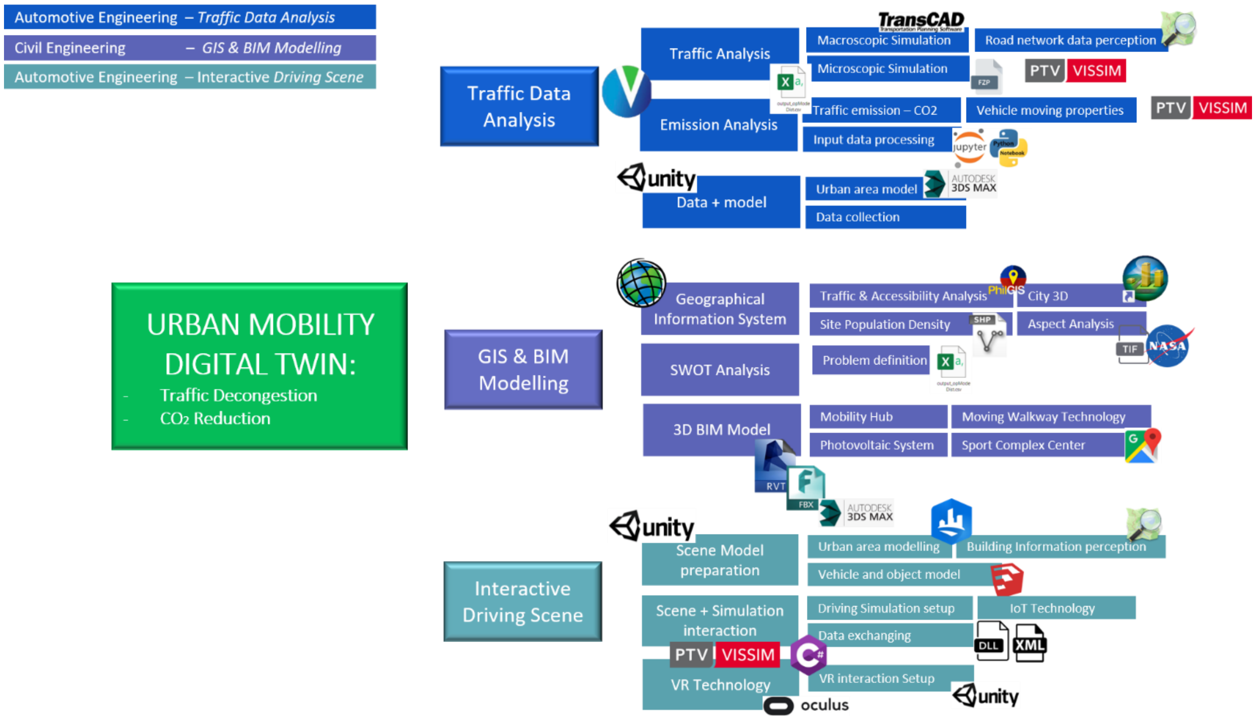



***Figure 11**: Research Methodology*

More in detail the workflow followed to fulfil tasks related to present thesis, so to civil engineering field, was the following. At first is introduced the case study focusing on geographical characteristics of the area and Philippines's history, then on population statistics, government's policies in terms of energy sources adopted and at last is treated the economy situation. Second, is defined the problem of concern for the analysed site of interest, that is urban mobility. To this aim, are carefully treated the Airport infrastructure of the Island, the poor service condition of the road network in the surrounding area and the problem related to traffic pollution and street safety. As third point of the methodology, it is addressed the data gathering process highlighting databases accessed for the different kind of information acquired. Moreover, it is given a theoretical overview of different data format which have been used from raster to vector datasets and are presented some preliminary analysis conducted to build a general working frame of the site. Following points concerns the execution of studies supposed of concern for mobility of the investigated area. Thus, the fourth point of the methodology is the use of GIS software, mainly *ArcMap* and *Arc-Scene*, for modelling and network analysis purposes. In detail, analysis concerned finding most efficient travel paths considering different impedances and traffic conditions and, on the basis of previous outcomes, identifying zone accessibility indices. Following, the S.W.O.T. analysis aimed at providing a scientific support, based on the analysis of the site, to stand for the realization of a specific development strategy to address the issue of urban mobility. Hereby, the explanation of the strategy showed by the decision-making process consisting in the realization of a smart mobility Hub. Then, considering both research fields working on Cebù case study, are shown main purposes of the intended implementation. Are outlined volumetric and typological elements supposed to be part of the Digital Twin which is fixed as a future development of the present work. Moreover, is addressed more in detail the strategy derived by the S.W.O.T. matrix describing services offered to mobility and highlighting two aspects, integration and sustainability of the development plan. At last, is presented the Hub model realized in *Revit* and are described design choices considered.

## 3.2 Case study

The case study of the present research was identified about the area adjacent to the International Airport of Cebù, located in the island of Mactan in the Archipelagos of the Philippines. The site of interest precisely includes the highly urbanized areas of Mandaue city, in the South-East of Cebù island, and Lapu-Lapu city located in the North of Mactan Island. These cities are not under provincial supervision but are often grouped with the province for geographical and statistical purposes. As previously outlined, literature and historical research were performed to properly characterize cultural heritage of the Country and its citizens.

### 3.2.1 Geography

The Philippines is an archipelago in the Pacific Ocean, north-east of Borneo, divided into three island groups named Luzon, Visayas, and Mindanao. These three main groups overall account for more than 300000 $km^2$ of territory and 7641 islands developing in a remarkable coastal which exceeds 36000 kilometres [59]. The main backbone of this myriad of islands is the Borneo mountain range, which not reaching the ocean level many times in its development to North-East direction, it results in the characteristic fragmented territory named Philippines. Given the volcanic origin the Philippines are largely mountainous although there are many flat areas especially in the inland river valleys. The main mountain ranges reach three thousand meters. In the island of Mindanao there are the two highest peaks in the Country, Mount Apo, a dormant volcano of 2954 m, and Mount Dulang-Dulang, 2941 meters tall. In the island of Luzon there is Mount Pulog which extends for 2922 meters. The archipelago is rather rich in waters, but obviously due to its morphology there cannot be many relevant rivers. The Cagayan, 505 km long, is the longest and flows in the northern part of Luzon. Follows Mindanao river, flowing for 373 km on the homonymous island, and the main tributary of the Cagayan, named Magat, which is located in the eastern part of Mindanao and flows for 353 km. There are many lake basins present, the major one is Laguna de Bay which extends for an overall area of 900 $km^2$ in south-east of Manila, then Lanao with an area of 347 $km^2$, the largest lake in Mindanao, and in third place the Taal, a volcanic origin lake of 234 $km^2$ in Luzon. The climate is tropical, hot and humid, heavily influenced by the monsoons but averagely annual temperatures are around 26-28 °C, with no significant variations from month to month. Philippines is characterized by a dry season in the first months of the year and a rainy season from May onwards. Between July and November, the Country is subjected to typhoons, particularly violent in central part.
Central Visayas region includes the islands of concern, Cebù and Mactan. Cebù Island is long and narrow, stretching 196 km from North to South and 32 km across at its widest point. It has narrow coastlines, limestone plateaus, and coastal plains. It also has rolling hills and rugged mountain ranges traversing the northern and southern lengths of the island. Mactan is a small island of nearly 65 $km^2$ located to the south-east of the main Cebù Island, it includes the cities of Lapu-Lapu and the municipality of Cordova. It is divided from the island of Cebù by the Mactan channel, crossed by the S. Osmenà bridge and the Marcelo Fernan bridge. Within the Central Visayas Region, these two islands with other 167 islands compose the Province of Cebù. From the national mapping and resource information authority of the "*Department of Environment and*

*Natural Resources*" was retrieved the *NAMRIA* topographic map in *Figure 12*. It was produced, at scale 1:250.000, by data from the Philippine and US Geodetic Survey, Army Map Service, Corps of Engineer, Bureau of Public Highways, and other agencies.

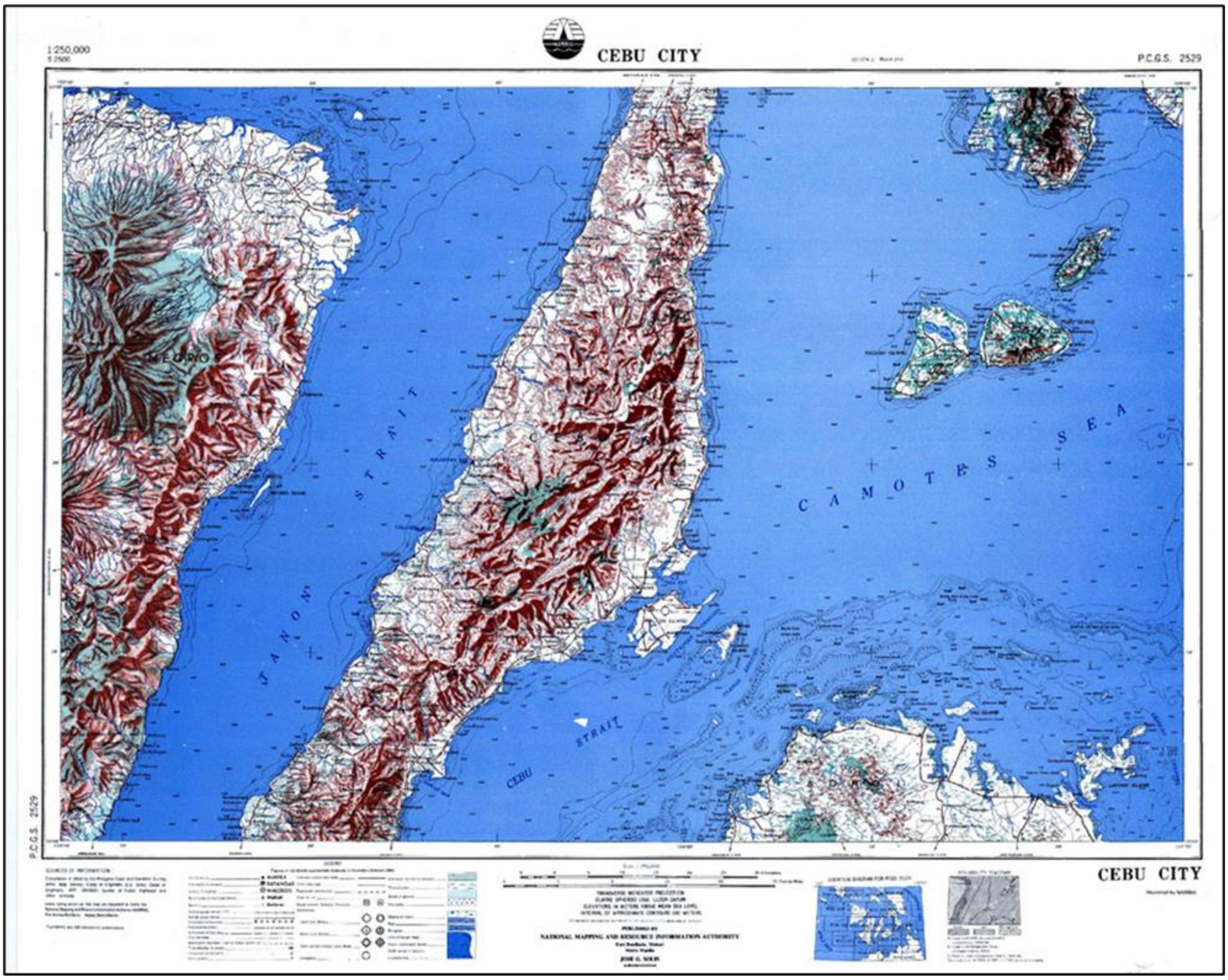



***Figure 12**: Cebù Island topographic map*

Source: Republic of the Philippines. National Mapping and Resource Information Authority. namria.gov.ph/products.aspx#topo

### 3.2.2 History

Philippines proclaimed its independence on June the 12th 1898 from the Spanish Empire, following the culmination of the Philippine Revolution. Nowadays it is a unitary presidential constitutional Republic, with the President acting as both the head of state and the head of government. The Spanish influence on the territory is strong since 1521 when the Portuguese explorer Ferdinand Magellan tried to circumnavigate the world. He landed on the island of Homonhon, then in Samar and Cebù. In the latter island visited, he established friendly relations with some local leaders converting some people to Christianity. However, Magellan was killed in 1521 in the battle of Mactan, fought against the local raja of Lapu-Lapu. Over the following decades other Spanish expeditions followed one another to the islands. In 1543 Ruy López de Villalobos led an expedition to the islands of Samar and Leyte which he named "*Las Islas Filipinas*" in honour of Philip II of Spain. Following the name was extended to the entire Archipelago. Spanish colonization helped make Philippines one of the three countries of Asia, together with Russia and East Timor, with a majority Christina. The 81% of people profess the Catholic religion while 12% follow other Christian faiths.

### 3.2.3 Population distribution

The State is administratively divided into 18 regions, of which the autonomous region of Muslim Mindanao, the Cordillera region and the district of the capital are special. There are more urbanized realities and others less, but at the Country level the urbanization rate of 49% indicates a rather homogeneous distribution between rural and urban populations. More than 20% of the population lives in the district of Manila, which has 1.780.000 inhabitants. Quezon City, with 2.935.000 inhabitants is the most populous city and it is included in Manila agglomeration. The other urban agglomerate over a million people is Davao City with 1.220.000 inhabitants on the island of Mindanao. Cebu City with 923.000 inhabitants is the main city on the smaller islands and the closest to the case study area of the research [60]. Philippines is a developing Country, its growth rate is among the highest in all South-East Asia. According to a computation based on the 2015 Census of Population and Housing and on 2020 and 2021 mid-year population projections, nowadays Philippines is supposed to count nearly 109.850.000 inhabitants [61], with a growth rate of 1.90% over the period 2000-2010 [60]. Limiting the analysis to Metro Cebù, the annual growth rate grows up to 2,2% for the five-year period 2010-2015 [62]. Population of Metro Cebù doubled during past two decades 1990-2010 and, according to the predictions of the Philippine Statistical Authority, will be doubling during the next four decades up to 2050, resulting in being about 5 million. However, due to limited land availability for urban land uses, the population growth rates of three major cities of Cebù, Mandaue and Lapu-Lapu will be gradually lessened and saturated, while the populations of neighbouring local government units will increase to be more than doubled. Data of 2015 Census about Metro Cebù population in the period 1990-2015 by city and municipality, provided by PSA, are described in *Table 2*.

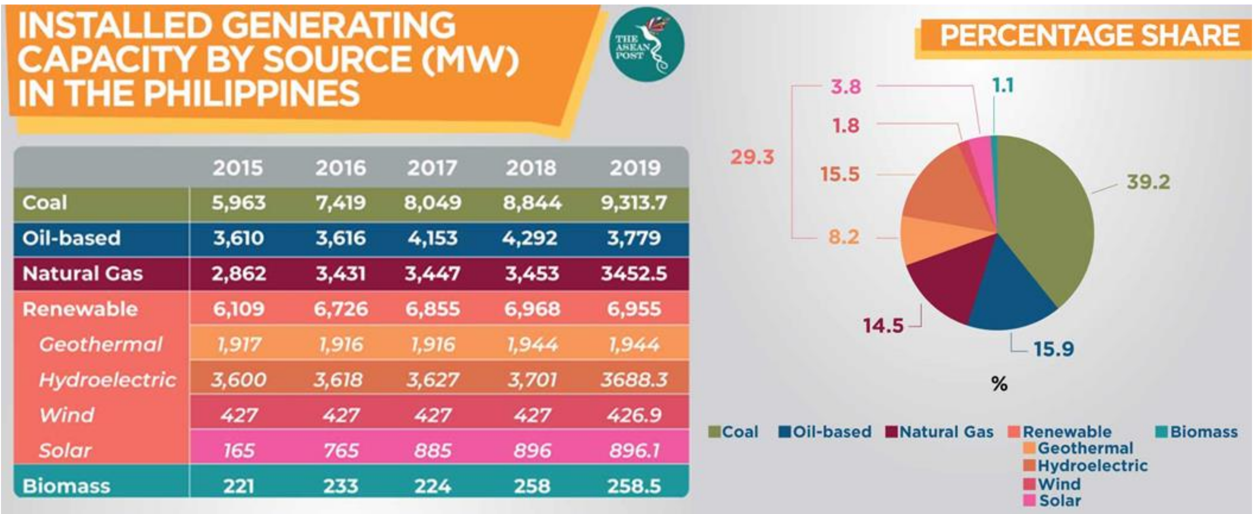
| City/ Municipality Name | Land Area (hectares) | No. of Brgy. | Population | | | | | Annual Growth Rate (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1990 | 1995 | 2000 | 2010 | 2015 | 90–00 | 00–10 | 10–15 |
| City of Carcar | 11,678 | 15 | 70,841 | 78,726 | 89,199 | 107,323 | 119,664 | 2.3 | 1.9 | 2.2 |
| Cebu City | 31,500 | 80 | 610,417 | 662,299 | 718,821 | 866,171 | 922,611 | 1.6 | 1.9 | 1.3 |
| Municipality of Compostela | 5,390 | 17 | 22,006 | 26,499 | 31,446 | 42,574 | 47,898 | 3.6 | 3.1 | 2.4 |
| Municipality of Consolacion | 14,720 | 21 | 41,270 | 49,205 | 62,298 | 106,649 | 131,528 | 4.2 | 5.5 | 4.3 |
| Municipality of Cordova | 1,715 | 13 | 22,331 | 26,613 | 34,032 | 50,353 | 59,712 | 4.3 | 4.0 | 3.5 |
| Danao City | 10,730 | 42 | 73,358 | 79,932 | 98,781 | 119,252 | 136,471 | 3.0 | 1.9 | 2.7 |
| Lapu-Lapu City | 5,810 | 30 | 146,194 | 173,744 | 217,019 | 350,467 | 408,112 | 4.0 | 4.9 | 3.1 |
| Municipality of Liloan | 4,592 | 14 | 42,587 | 50,973 | 64,970 | 100,500 | 118,753 | 4.3 | 4.5 | 3.4 |
| Mandaue City | 2,518 | 27 | 180,285 | 194,745 | 259,728 | 331,320 | 362,654 | 3.7 | 2.5 | 1.8 |
| Municipality of Minglanilla | 6,560 | 19 | 50,875 | 62,523 | 77,268 | 113,178 | 132,135 | 4.3 | 3.9 | 3.1 |
| City of Naga | 10,197 | 28 | 60,425 | 69,010 | 80,189 | 101,571 | 115,750 | 2.9 | 2.4 | 2.6 |
| Municipality of San Fernando | 6,939 | 21 | 35,051 | 38,700 | 48,235 | 60,970 | 66,280 | 3.2 | 2.4 | 1.7 |
| Talisay City | 3,987 | 22 | 97,955 | 120,292 | 148,110 | 200,772 | 227,645 | 4.2 | 3.1 | 2.5 |
| **Metro Cebu** | **116,336** | **349** | **1,453,595** | **1,633,261** | **1,930,096** | **2,551,100** | **2,849,213** | 2.9 | 2.8 | 2.2 |

***Table 2**: Population metro Cebù by city and municipality in 1990-2015*

Source: Philippine Statistical Authority. Population Census (2015)

### 3.2.4 Energy

Like many other developing Countries in the World, the Philippines faces twin challenges of population growth and rising energy demand. The theme about population was carefully introduced in sub sub-chapter 3.2.3 but not as well the theme about energy. Coal is the dominant energy source for Philippines, but the State is dependent on imports for nearly 75% of its supply, [63] most of it from Indonesia and Australia. Such political approach exposes the country's electricity system to price volatility and the risk of unfavourable foreign exchange rates. Coal accounts for the 52% share in gross power generation as of December 2018, followed by renewable energy sources like geothermal, hydro, solar, and wind, with 22% and natural gas at 21% [63]. While it is the cheapest fuel choice coal is also the most polluting one. Because of well-known human-health hazards by coal plant emissions, the Government of Philippines is introducing various policies to foster the use of renewable energy. Some of the policies regard income tax holiday up to 7 years and duty-free import of equipment for renewable energy technologies. Despite of such policies to promote renewable sources of energy, a recent report by the environmental group "*Greenpeace*" detailed how five of the Country's biggest energy companies plan to increase their coal portfolios in the next two to six years.
In *Figure 13* is shown the study conducted by *Greenpeace*, reported by "*The Asean Post*" website, about different energy sources present in the Philippines. By the pie chart is clear the greater share of coal with respect more sustainable and eco-friendly solutions represented by renewable sources like solar, wind, geothermal and hydroelectric source, which overall counts for nearly the 29,3% [63].




| | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| Coal | 5,963 | 7,419 | 8,049 | 8,844 | 9,313.7 |
| Oil-based | 3,610 | 3,616 | 4,153 | 4,292 | 3,779 |
| Natural Gas | 2,862 | 3,431 | 3,447 | 3,453 | 3452.5 |
| Renewable | 6,109 | 6,726 | 6,855 | 6,968 | 6,955 |
| Geothermal | 1,917 | 1,916 | 1,916 | 1,944 | 1,944 |
| Hydroelectric | 3,600 | 3,618 | 3,627 | 3,701 | 3688.3 |
| Wind | 427 | 427 | 427 | 427 | 426.9 |
| Solar | 165 | 765 | 885 | 896 | 896.1 |
| Biomass | 221 | 233 | 224 | 258 | 258.5 |

***Figure 13**: Greenpeace study on energy sources in Philippines*

Source: Greenpeace. https://theaseanpost.com/article/why-philippines-so-focused-coal

### 3.2.5 Economy

Philippines is an open economy, it trades with Countries such as Japan, the United States, China, South Korea, and Germany which are its top export markets. As reports the official website of the National Government, the Country's primary exports include electronics, semiconductors, transport equipment, construction materials, and minerals [59]. One of the leading sectors, of course, is the tourism. The Country was host to a record high of 8.2 million foreign tourists in 2019 [59]. As far as Cebù Island, tourism give big shares to region economy. Because of their beautiful islands, white sand beaches, luxury hotel and resorts, diving locations and heritage sites, high domestic and foreign tourist arrivals have fueled the tourism industry of Cebù. The Island of Mactan is known for its industrial plants which are among the most successful enterprises in the Nation. Many of them are located in the Mactan Export Processing Zone (MEPZ), a tax-free industrial zone inaugurated in 1979. Moreover, the Cebù-Mactan International Airport, the second largest in the nation, is located on the Island.

Considering the entire Metro Cebù, as it is reported by the study for sustainable urban development in Metro Cebù, the growth potentials of economic activities up to 2050 were projected. Cebuanos wealth level, in terms of Per Capita Gross Regional Domestic Product, will be uplifted to be more than 20,000 USD in 2050. The Per Capita GRDP index for Metro Cebu will grow at 8.3% per annum in the period 2010-2020, while will grow at 7.8% per annum in the period 2020-2030, and then 5.8% per annum between 2030 and 2050. In practice, economic activities in Metro Cebù will be almost 15 times larger than the present level as of 2010. As far as job opportunities, the study for a sustainable urban development of Metro Cebù suggest a total of 2 million employments more available by 2050. Moreover, the structure of employments is supposed to shift to a more industrialization-oriented structure driven by urban service sectors because of economy diversification intents. Indeed, urban economy diversification is considered a must for the sustainable development in programme, and within the plan it is promoted by inducing more foreign direct investments as well as by encouraging local investors in various potential business areas [64].

The chart in *Figure 14* shows the comparison of Per Capita GRDP, Gross Regional Domestic Product, among Asian Countries in 2010, including Metro Cebù, and Metro Cebù GRDP projections for 2050.

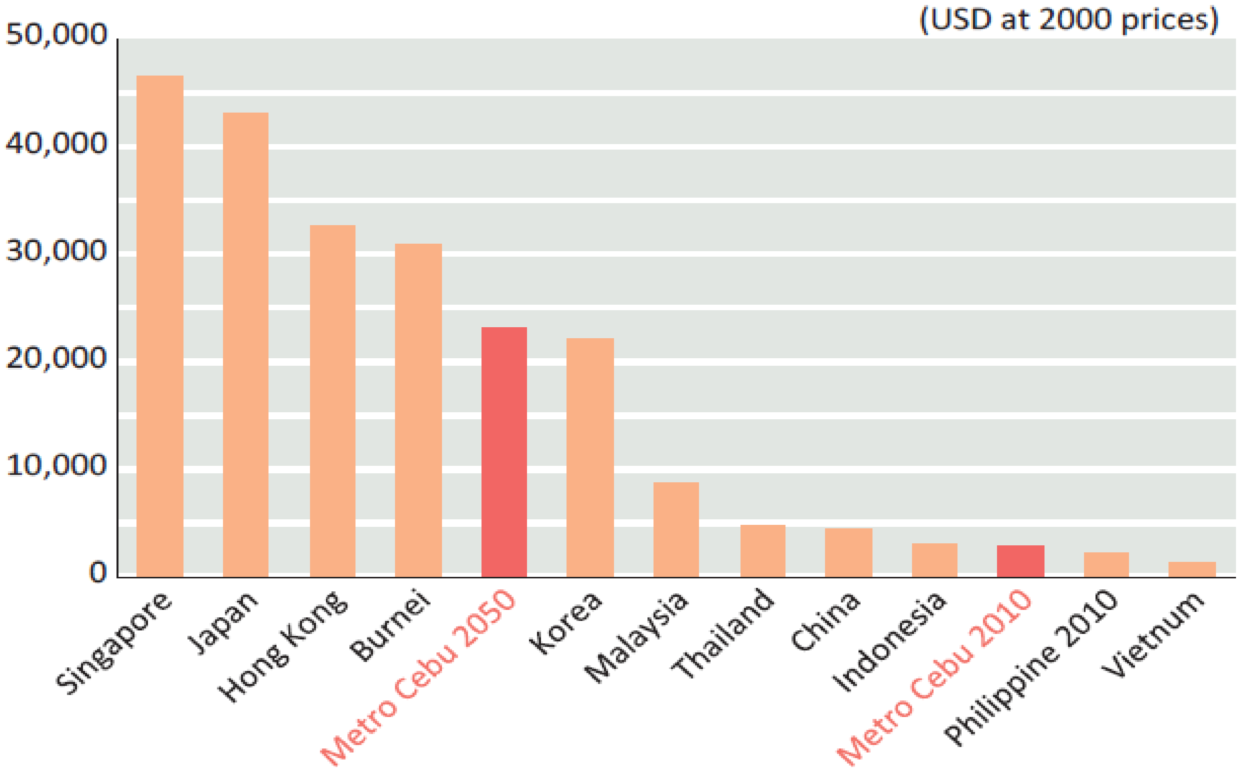



***Figure 14**: Comparison of Per Capita GRDP among Asian Countries in 2010 and Metro Cebù*

Source: JICA, MCDCB. The road map study for sustainable urban development in Metro Cebù

## 3.3 Problem definition

Having completed a general description of Philippines region, within the present sub-chapter conceptually the investigation area is narrowed down to finally restrict and define the focus of the present research to then start with data collection process. To this objective, first are presented some global data by United Nations research on transport demand and its implications on cities. Second, having introduced the problem is identified the smart mobility as the focus of the paper, and at last are investigated the mobility related aspect for the case study of Cebù urban environment, from the Airport infrastructure to the surrounding road network.

According to data collected by the UN [4], and as it was reported within Chapter 1, for the period 2030-2050 it is estimated a significant worldwide population growth as a result of which city inhabitants will peak at nearly 6.7 billion, making record an increase up to 66% by the year 2050. One of the first implications of the increase in urban population is the consequent and natural increase in urban mobility demand as far as passengers and goods. Urban mobility is the ability of an individual to move within an urban space in an organized and meaningful manner, in line with their physiological, intellectual, and socioeconomic needs and by using the available transport, community, and information communication infrastructure [65]. According to the research conducted by the UN and the data reported within the magazine "EcoScienza" by Arpae [66], it is estimated by the year 2050 a demand for urban passenger mobility double compared to 2010 and, by the same year, a tripled demand for urban freights transport.

In *Figure 15*, derived by the EcoScienza magazine of December 2019 by Arpae [66], is reported data described so far in terms of urban population growth for the next decades and urban mobility demand of people and goods for the period 2010-2050. As far as the increasingly urbanization trend, it is shown the CAGR, that is the compound annual growth rate recorded in such window of time.

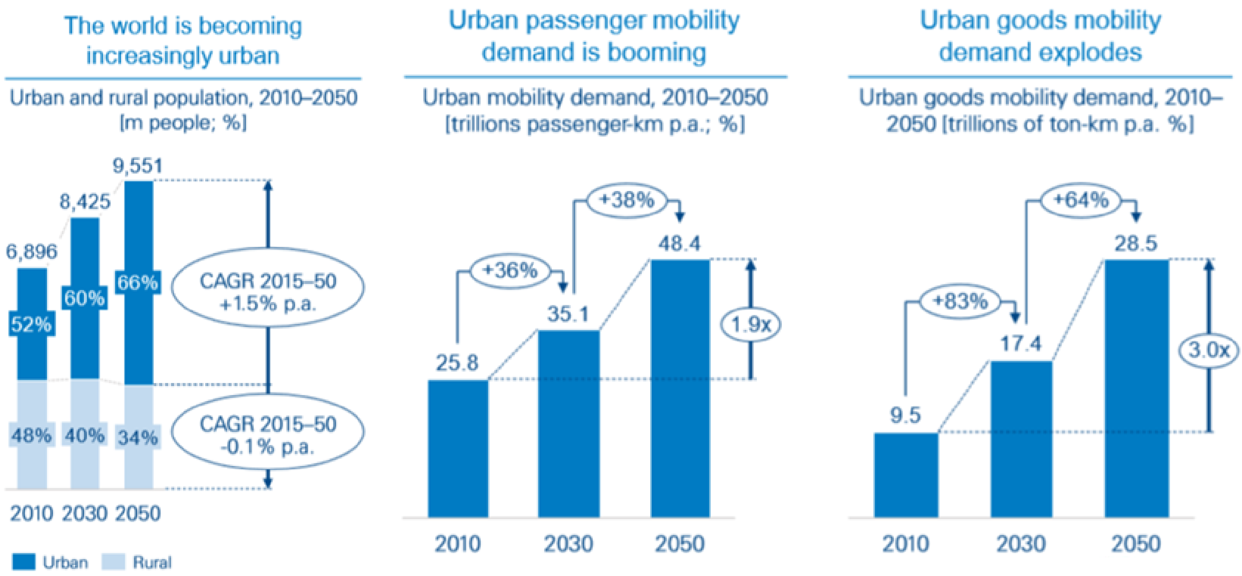



***Figure 15**: Growth forecasts of urban population and urban mobility of people and goods*

Source: G. Luppino. Migliorare l'efficienza della logistica urbana. (2019). ARPAE

The urban transport sector plays a fundamental role in the city economy, however negative impacts on people and natural environment deriving from it cannot be ignored. The increase in population and in demand for mobility is accompanied by a higher level of city traffic. This traffic condition causes congestion which is one of the most well-known effect of urbanization. As already explained in sub sub-chapter 1.1.3 "*Urban related issues*", the increment of traffic

congestion within a city has many side effects which deserve attention. Particular care is posed on two interconnected themes, the efficiency of the mobility network and the level of pollutants as well as atmospheric $CO_2$ deriving from traffic. Indeed, traffic jams in a crowd environment on one side affect the efficiency of the city road network system, causing logistic delays due to traffic accidents with long vehicle queues and inefficiencies on public transport services, while on the other side contribute to increase the pollution and the emission of $CO_2$ in the natural environment. As reported in sub sub-chapter *1.1.3 "Urban related issues",* the transport sector is responsible for the 23% of world $CO_2$ emissions from fossil fuel combustion [12]. This large impact is due to a truly high traffic level, however for developing Country, such as the Philippines, is even more significant the contribution by old vehicles with high emission rate.
From cities perspective, to cope with such an increase and to keep step with changes it is necessary that the existing mobility infrastructures and those in planning, such as roads, highways, parking and whole urban areas, are organized, designed and finally managed in an insightful way with particular care on efficiency aspects of their usages. Since usually there is no further available space to widen streets or add new rail lines because either of environmental reasons or economic aspects, often the only strategy pursuable is a better management of the existing network. Moreover, governments should activate a set of policies devoted to foster green transportation and in general sustainable solution to urban mobility, from the simplest renovation of old and run-down citizens vehicles and public fleet to more innovative and technological options. Non-motorised means of travel or vehicles powered by alternative fuels is a solution but also increase the use of public transportations systems to decrease the use of personal vehicles can be a strategy. Thus, the aim of such approach is double and concern the improvement of the network efficiency lead by a correct planning and management of it and the reduction of traffic pollution acting on power vehicles technology, urban transport policies and network management strategies as abovementioned. Urban development in this case must therefore have as its main objective that of improving the efficiency of vehicles and enhance pedestrians and freights mobility within the city taking into account commercial and production activities throughout the territory. At the same time the development must be sustainable in accordance with the 17 Sustainable Development Goals by the UN 2030 Agenda, not impacting the natural environment, by traffic perspective for the case study of interest.

### 3.3.1 Smart Mobility

Based on the aspects abovementioned, the attention of the research was drawn on the concept of smart mobility and the possible improvement solutions of the entire urban mobility infrastructure of Mactan. Having in mind the more general aim of improving people quality of living within the city, the possible initiatives of smart mobility may also represent a leading strategy for the entire Country. Smart mobility may be presented together with smart economy, governance, people, living and smart environment as one of the basic pillars of any Smart City initiative which is enabled by the application of information and communication technologies. The main objective of a city smart mobility is the enhancement of people and goods flow, which allow for a:

- Reduction in traffic congestion,
- Reduction in travel time,
- Reduction in traffic pollution and emission,
- Reduction in mobility costs,
- Improvement in mobility safety.

The term smart refers, among the other meanings, to a sustainable mobility of people, vehicles and goods in the environment. A self-sustainable mobility of an urban environment is an important and integrated part of social and economic life, as hinted above, directly affecting the economy and life quality especially in large city agglomerations. In *Figure 16* are presented basic pillars of a smart city and information and communication technologies enabling it [67].

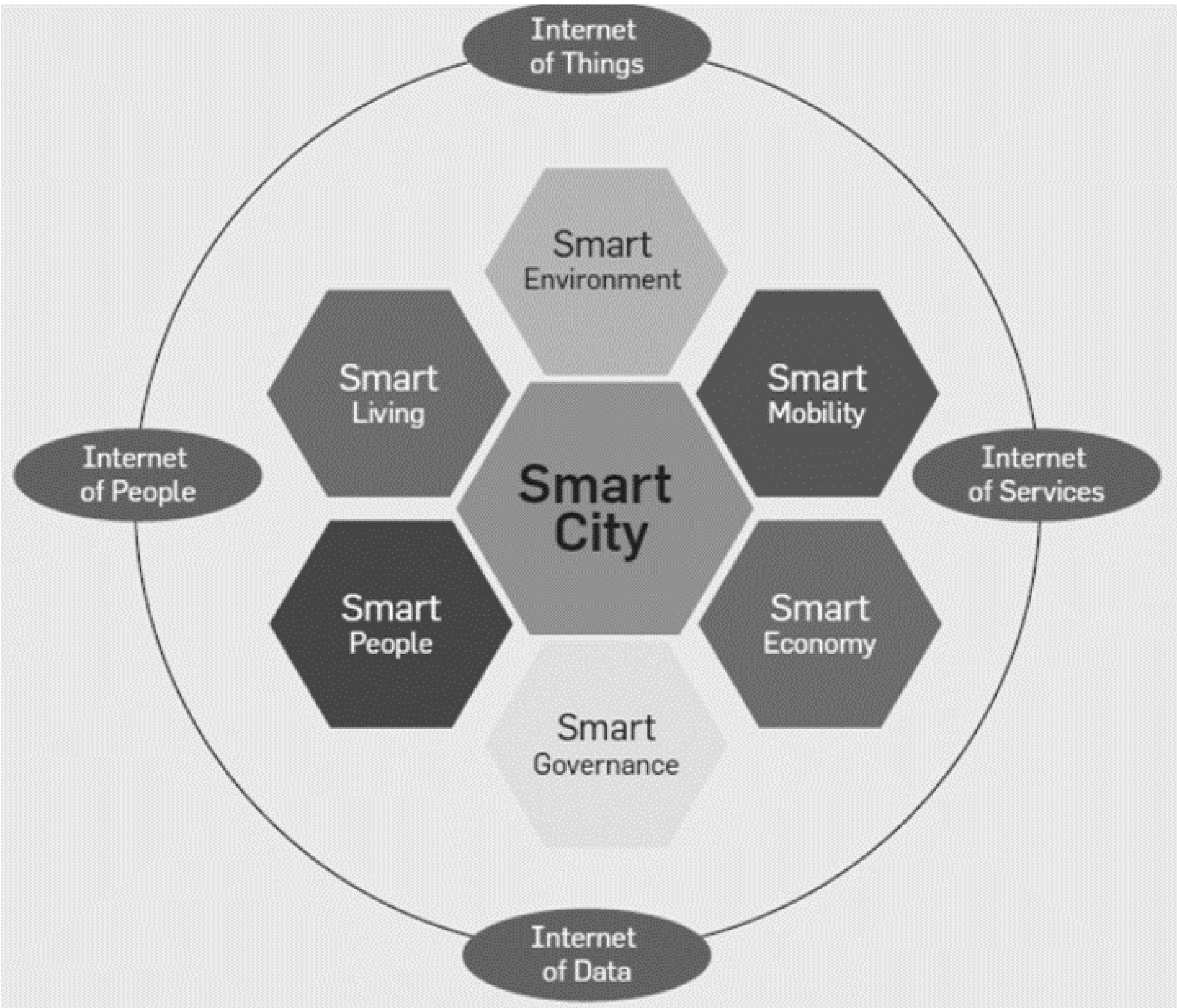



***Figure 16**: A smart City Model*

Source: R. Khatoun and S. Zeadally. Smart cities: concepts, architectures, research opportunities. (2016)

Smart mobility is often seen as largely permeated by ICT to support the optimization of traffic fluxes and to collect citizens 'opinions about liveability in cities or quality of local public transport services [68]. In sub-chapter 2.3 "*Smart City*" it was distinguished the concept of automatization from smart. For the specific case of mobility, the same reasoning applies, so it is necessary to distinguish between intelligent transport systems and smart mobility. Intelligent transport systems are oriented on enabling services but without embedded machine intelligence and without any contributions by citizens. On the other hand, smart mobility is focused on citizens aiming to increase city quality of living with particular attention on energy efficiency and sustainability.

In order to identify weaknesses and strengths of the transport system, to identify key or critical elements, provide insight into the state of urban mobility, enable better understanding of urban mobility, and create a foundation for improvement of existing and creation of new services in the Intelligent Transport Systems (ITS) area, urban mobility needs to be assessed [69]. The idea consists in developing a smart mobility solution which is comprehensive of all abovementioned aspects, from the enhancement of urban mobility of the region, in terms of traffic reduction and multimodal solutions, to the development of a sustainable and sharable approach in a smart governance manner. Therefore, the understanding of key urban mobility features has an extremely important role from the perspective of a sustainable urban transport development plan which is in line with the objectives of reducing traffic congestions, mitigating negative environmental and health impacts and achieving transport-related time and cost savings.

### 3.3.2 Mactan Mobility

To address the abovementioned aim, case study aspects which have drawn the research attention, and which were useful for defining the principal focus of the investigation are introduced and analysed. Particular care is given to the central role of the International Airport of Mactan, weaknesses of the actual road network infrastructure of the Island together with crowding condition of the environment, the traffic level of the existing bridges connecting Mactan and Cebù islands and finally the high emission class of public transportation fleet.

*Mactan-Cebù International Airport & Road Network*
The Mactan-Cebu International Airport located in the city of Lapu-Lapu on Mactan Island, is the second busiest international Airport in the State. The runway was built by the United States Air Force in 1956 as an emergency airport for strategic air command bombers and it was known as the Mactan Air Base. It remained a spartan outpost until the mid-1960s when the civilian Airport was opened to replace the now closed Lahug Airport in Cebù city. Nowadays the Airport is composed by two terminals. Terminal 1 was built in 1990 and it serves as the airport's domestic terminal. Prior to the completion and opening of Terminal 2, which took place on 1ST July 2018, it housed both domestic and international operations with an annual capacity of 4.5 million passengers. Terminal 2, built between 2016 and 2018, is the newest Airport terminal and since its opening it increased the capacity of the Airport to 12.5 million passengers per year. It currently handles all international flights. The design of the new terminal has timber arches that look like an inverted boat hull and a wave-like roof that evokes a tropical and resort-like feel describing the sea waves surroundings the Island of Cebù. The international terminal, whose design engineer Giuliano Pairone participated in, won an award for the category "Completed Buildings – Transport" at the World Architecture Festival in 2019.
The Mactan International Airport was considered a key feature of urban mobility within the present research because it represents a very crucial node in terms of economy of the Island which is mainly based on tourism industry. Since 2018, when the new Terminal 2 was opened, the Airport plays even a more a crucial role as far as the urban mobility system. Indeed, having Terminal 2 increased the capacity of the Airport up to 12.5 million passengers per year and consequentially concentrated a higher quantity of vehicles in a limited portion of territory, it has had, and continues to exercise, a direct influence on the mobility infrastructure of the Island. As mentioned in sub-chapter 3.2 "*Case Study*", the Country official website reports that Philippines was host to a record high of 8.2 million foreign tourists in 2019 [59]. Moreover, considering the Airport as one of the most important infrastructure in Cebù region, it was capable to attract business investment nowadays resulting in many commercial activities, for the majority based on tourism, in the surrounding area. So, the Airport increased also indirectly the centrality of this area for the urban mobility system under investigation. As a result of that, from the territory surrounding the Airport start and end the majority of daily car, truck, motorbike and bus trips,

having a strong impact on the transport network system, and generally trips depend upon the direct and indirect influence of the International Airport of Mactan. To ensure that the expected huge flow of vehicles, pedestrians and goods is adequately supported by transport network as well as to allow public services working properly, the area adjacent to the Airport must be adequately conceived, organized and designed in terms of mobility, giving particular emphasis on road network, bridges and means of transport. After the proper conception and design, what becomes central is the smart governance of these infrastructures, which then must be managed properly to make tourism a concrete possibility of development for Metro Cebù exploiting at its best the potential offered by the high number of annual tourists. In following figures is shown the timber arch structure, *Figure 17*, and the wave-like roof, *Figure 18*, peculiarities of the Airport design which were rewarded at the World Architectural Festival in 2019.

***Figure 17****: International Airport T2, timber arches structure*

Source: https://www.archdaily.com

***Figure 18****: International Airport T2, wave-like roof*

Source: https://www.schmid-screw.com

*Road network and street crowding*

In order to function properly an urban infrastructure must be first of all satisfactory for users. This also applies to the road network which must guarantee the safety of pedestrians and motorists together with functional requirements. Currently, when passengers land in the Island and exit from the Airport terminal they find a mess in the surrounding area. Indeed, the road network is not sufficiently extended and branched to support the entire traffic to and from the Airport, the majority of streets are dirt roads with no traffic lights and, where road pavements exist, they are neglected and not properly maintained. The report on Country Road network condition based on 2013 data and carried out by the Department of Public Works and Highways of the Philippine Republic in 2014, shows a non-idyllic situation of Country's roads. Indeed, as it is described in *Figure 19,* in terms of road length just the 27.7% is paved and if we address barangay roads, which overall count for the 46% of the total roads, the percentage of paved roads lowers to 6.6% [70]. The condition in terms of percentages of the whole Archipelago can be also generalized to Mactan case study.

**Condition of Philippine Road Network:**

**Based on 2013 Road Condition Data**


| | |
|---|---|
| 300,000 sq. km | Total Land Area |
| 215,717 kms | Total Overall Road Network |
| *32,227 kms* | *Total National Road Length* |
| 0.72 km/sq. km | Road Density |
| 0.20 km/sq. km | Paved Road Density |
| 0.27 | Overall Paved Road Ratio |
| 0.83 | Paved Road Ratio for Nat'l. Roads |

| | Total (Km.) | Unpaved | Paved | % |
|---|---|---|---|---|
| *National Road | 32,226.9 | 5,454.0 | 26,772.9 | 83.1% |
| *National Arterial* | *16,078.7* | *1,226.5* | *14,852.2* | *92.4%* |
| *National Secondary* | *16,148.2* | *4,227.5* | *11,920.7* | *73.8%* |
| Provincial Road | 31,233.2 | 21,457.6 | 9,775.6 | 31.3% |
| City Roads | 14,739.4 | 5,537.6 | 9,201.8 | 62.4% |
| **Municipal Roads | 15,816.0 | 10,422.0 | 5,394.0 | 34.1% |
| **Barangay Roads | 121,702.0 | 113,682.0 | 8,020.0 | 6.6% |
| Total: | 215,717.5 | 156,553.2 | 59,164.3 | 27.4% |

**Based on 2013 Road Condition Data*

***As of 2002*

2

***Figure 19**: Condition of Philippine Road network*

Source: Department of Public Works and Highways. DPWH Strategic Infrastructure Policies and Programs. (2014)

Moreover, it must be considered that streets of Mactan Island and Mandaue city are crowded with vehicles but also with people, mainly children. This traffic conditions tends to inhibit the free flow of vehicles and often leads to accidents blocking the entire mobility which is entirely sustained by few principal road links. Since the Philippines is experiencing a strong demographic development and the phenomenon of urbanization, as described in sub sub-chapter *3.2.3 "Population distribution"*, the presence of people in the urban environment in the coming years could increase significantly, inhibiting more and more traffic safety and urban mobility efficiency because of the onset of traffic congestions and long queues of vehicles.

*Bridge infrastructures*

The Island of Mactan is divided from the island of Cebù by a sea channel, which is crossed by two bridges built in different epochs to connect the smaller Island to the city of Mandaue. The construction of the oldest, Sergio Osmeña bridge, began in 1970 while the Marcelo Fernan bridge was built in the 90s to decongest the traffic from the former infrastructure. These two bridges are quite different from each other. The S. Osmeña Bridge, presented in *Figure 20*, is a truss bridge characterized by two lanes and one pedestrian sidewalk for a total length of 864m. It sits astride the northern end of the Mactan Channel, which is a gateway to the Cebu International Port, where about 80% of domestic and international shipping operators and shipbuilders reside.

***Figure 20**: Sergio Osmenà bridge, truss structure*

Source: Wikipedia

***Figure 21**: Marcelo Fernan bridge, extradosed cable-stayed structure*

Source: Flickr

The Marcelo Fernan bridge, located about 1.6 km north of the older deck, has an extradosed cable-stayed structure made of prestressed concrete. It is currently the longest cable-stayed bridge in the Country. It has a total length of 1,237 meters with a center span of 185 m, and it is composed by four lanes for vehicles and two pedestrian sidewalks. The Marcelo Fernan bridge, presented in *Figure 21*, was opened in August 1999 to decongest the traffic from the older transportation infrastructure. However, nowadays due to population growth, urbanization and also the presence of the new International Airport which has caused a significant increment in urban mobility demand, the Fernan bridge is no more sufficient to streamline traffic to and from the area surrounding the Airport. The traffic level of the two bridges, which as mentioned above serve as a link between the larger Island of Cebù and the smaller Island of Mactan, is another transport infrastructure related aspect to be taken into consideration. Currently, the two bridges are insufficient to handle traffic to and from Mactan Island making it two preferred points for traffic jams onset which hinder both the Island's mobility and the access to the Airport infrastructure. In recent years, many studies were done to evaluate the level of congestion of these bridges given the volume of traffic and the road capacity. All these investigations agree on the oversaturation state of the Osmenà bridge, while the Marcelo-Fernan bridge is becoming saturated since the renovation of the Mactan Airport. Accordingly, is currently being built a third bridges on the North of the Island which is supposed to streamline traffic and increase the transportation infrastructure of the entire Region.

*Means of Transport*

Within previous paragraph it was repeatedly highlighted the risk that the aspects treated so far represent for traffic congestion of the whole area of investigation. As it was explained in sub sub-chapter *1.1.3 "Urban related issues*", traffic congestion is one of the most well-known effects of population growth and the consequent urbanization, which significantly overburdens the natural environment. Indeed, traffic jams cause hours of queue for short journeys hindering urban mobility and increasing the level of traffic pollution, which then lead to the reduction of air and water quality. Moreover, considering that means of transport commonly used for travelling are not sustainable and eco-friendly, but old taxis, motorcycles or jeepneys, there is a great environmental impact due to the large amount of $CO_2$ emission. Particularly harmful for the environment is the use of jeepneys, the highly decorated and open buses of Philippines which can carry up to 15-22 passengers each travel. Actually, were counted nearly 300.000 jeepneys throughout the whole archipelago and they represent the major source of pollution of the Philippine. These jeeps are the most popular means of public transport in the Nation because represent a symbol of cultural heritage and art for people. Endika Aboitiz during a speech about the renovation of jeepneys defined them as the homologous of London's double-decker buses, a moving museum [71]. The widespread use of these vehicles is also associated with the low travelling cost for local people, whose may buy a ticket for nearly 8-9 pesos which correspond to 0,13-0,15 euro. They originate from old military jeeps used by the US military during World War II and because of that are truly backward from the technological point of view. Indeed, since 2017 to tackle the problem of air pollution, at the local level, and road safety the State President started the process to abolish these jeeps by replacing them with a new fleet of electric public buses. In some regions these electric buses are already running, however there have been many protest marches by Philippines' population throughout the entire Country about these measures which, according to people thoughts, want to destroy a national symbol of cultural heritage.

## 3.4 Data collection

Having fixed and explained the focus of the current study, it was necessary to collect all data considered of interest aiming to carry out a complete and comprehensive analysis on urban mobility infrastructure of the study area and, as result of investigation outcomes, adopt and pursue some valuable strategies of urban mobility development. For the management of data were used ArcMap and Arc Scene, two specific ESRI application devoted to georeferenced data. ArcMap was used for the construction of a working frame of the area of interest to be used for the following analysis about itineraries optimization and free-obstacles paths definition, while Arc Scene is a 3D visualization application used within the research in order to realize, visualize and consequentially make analysis on a 3D mass model of the site under investigation.

### 3.4.1 Data source

A first distinguish must be traced among spatial and non-spatial data sources:
Non-spatial datasets are literature and historical data on Country statistics and other official information which can be used to build a general framework of the area under investigation or as auxiliary information for specific spatial analysis. As far as the case study, non-spatial data of concern regards Country information about population distribution and density by region and city, local laws in force about speed limits as well as the national road classification and other mobility related aspects. Non-spatial data were obtained from an online research conducted consulting official agencies such as the PSA, Philippines Statistics Authority, the Philippine Government website, and the associated Departments, in particular the Department of transportation. Other qualitative information about the site was obtained from a simple navigation on google maps.
Spatial datasets are georeferenced information about any area in the World which are fundamental to perform some specific site analysis according to different purposes. For these kinds of information were used sources which resulted being the most reliable ones, mainly *NASA* website and *PhilGIS* website, an open source of Philippine GIS data for educational and non-profit activities.

| Web Source | Source Description | Web Link | Data | Format | Reference System | Data Source | Accessed Date | Final obtained data |
|---|---|---|---|---|---|---|---|---|
| Phil GIS | Open Philippine GIS data for educational and non profit use. | http://philgis.org/general | Country Boundary | .shp .dbf ,prj . xml . cpg .shx | GCS_WGS_1984 | GADM | 20 – Oct- 2020 | Phillipine Map |
| | | | Country Regions | .shp .dbf ,prj . xml .cpg .shx | GCS_WGS_1984 | GADM | 20 – Oct- 2020 | Central Visayas Map |
| | | | Country Provinces | .shp .dbf ,prj . xml .cpg .shx | GCS_WGS_1984 | GADM | 20 – Oct- 2020 | Province of Cebù |
| | | | Country Cities | .shp .dbf ,prj . xml . cpg .shx | GCS_WGS_1984 | GADM | 20 – Oct- 2020 | Cities of interest |
| | | | Administrative Boundaries (Barangays boundaries) | .shp .dbf ,prj . xml . cpg .shx | GCS_WGS_1984 | GADM | 20 – Oct- 2020 | Mandaue and Lapu-Lapu city subdivision by Barangays |
| | | | Roads | .shp .dbf ,prj . xml . cpg .shx .osm | GCS_WGS_1984 | Geofabrik GmbH-OpenStreetMap | 28- Oct - 2020 | Road Network |
| | | | Population Demography | .shp .dbf ,prj . xml . cpg .shx | GCS_WGS_1984 | | 25 – Oct - 2020 | Population Densisty Thematic Map |
| NASA | National Aeronautics and Space Administration | | SRTM DEM | .jpg .jgw | GCS_WGS_1984 | NASA | 6- Nov - 2020 | Digital Elevation Model |
| University of Tokyo | Institute Industrial Science | http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_DEM/index.html | DEM | .tiff .tfw | GCS_WGS_1984 / EGM96 | - NASA SRTM3 DEM.<br>- JAXA AW3D-30m DEM.<br>-DEM Viewfinder Panoramas | 6 – Nov - 2020 | Digital Elevation Model |
| EORC - JAXA | Advanced Land Observing Satellite | https://www.eorc.jaxa.jp/ALOS/en/aw3d30/index.htm | DEM | GEOTIFF | GCS_WGS_1984 | ALOS – Remote sensing for stereo mapping | 6 – Nov – 2020 | Digital Elevation Model |
| ESRI | International supplier of Geographic Information | / | Base Map | .jpg .jgw | WGS_1984_UTM_Zone_51N | ESRI | 04 – Nov - 2020 | Map Support |

***Table 3**: Spatial database accessed during the research development.*

In *Table 3* are summarized databases used for the study with the corresponding data format, the last accessed date and the reference system adopted. Based on such data during the research development were produced the files hinted in the last column of the table, then precisely described in the remaining part of the present paper. For what concern the collection process of georeferenced data, in the following sub sub-chapters are described the acquired information considering usages in the following analysis phase and are given some theoretical definitions about distribution format. In detail, it was necessary to obtain a raster data about the digital elevation model of the terrain, a vector data in the format of a shapefile describing the existing road network in the area of concern with the relative attribute table, the road classification with speed limits in force, and last the geometric subdivision related to the administrative boundaries of Mactan Island.

### 3.4.2 Raster Data: Digital Elevation Model (DEM)

Raster data is used to represent continuous phenomena such as elevation, temperature and air quality for instance. These kinds of dataset allow to have a general picture of an area because are continuous models describing not only the single entities but also what is in the surrounding of the objects pictured. Raster may be more convenient when performing multi-temporal or spatial analysis since it is easy to apply a mathematical function to the entire matrix. A raster is defined by its resolution which is governed by the selected pixel size chosen on the base of the final objective, the scale of the model and the density of the available observations.
The DEM is a continuous raster model which describe precisely the physical surface of the terrain, highlighting the elevation characteristics of an area. Within the present project, since the digital elevation model obtained was mainly flat, the DEM was just used as support of the analysis, but it was not really significant for the analysis itself. Moreover, they were downloaded two different raster datasets from two different data sources, to then focus on the DEM characterized by the highest resolution. The different datasets consulted, and now treated in the paper, are the "*NASA Model*" and the "*MERIT Model*".

*NASA Model*
By exploiting the downloadable data from *PhilGIS* website, the first elevation map was realized on the base of *NASA* observations. This online platform allowed us to access a huge dataset containing many variables coming from different sources, such as data by *NASA,* the major provider for publicly and freely available DEM and DTM. The Current SRTM DEM product is still nowadays the most downloaded dataset in *NASA* history, it is characterized by 3 arcsec spacing resolution and has about 100 m and 1 m over US of precision. In detail, for Mactan Island case study, once the area of interest was defined on the dashboard, it was selected the 2007 version "*NASA Shuttle R.T. Mission Global 3 arc second V003*".

*MERIT Model*
However, by searching on the web it was found a research product developed by the Institute of Industrial Sciences of the University of Tokyo called "*Multi-Error-Removed Improved-Terrain DEM"*. This model is characterized by a higher resolution than *NASA* product because it was developed by using multiple satellite datasets and by removing multiple error components from the existing spaceborne DEMs are fundamental input for many geoscience studies, but however they still include non-negligible height errors. By filtering several products as baseline data, it was possible to finally get a high accuracy global DEM at 3 arcsecond resolution which was free

of absolute bias, stripe noise, speckle noise, tree height bias. Products which were processed to obtain the final elevation model were the following:

- NASA SRTM3 DEM v2.1
- JAXA AW3D-30m DEM v1
- Viewfinder Panoramas' DEM

After processing to remove errors, by comparing the *NASA* model and the *MERIT DEM* just discussed were found significant improvements in flat regions or for landscapes such as river networks and hill-valley structures where height errors larger than topography variability became clearly visible [72].

### 3.4.3 Vector Data: Road network & Administrative boundaries

Vector data is used for the description of discrete features which are represented using lines, points, polylines and polygons in a precise manner. Indeed, they allow to address the shape of reality better than raster. Moreover, for definition a vector data is always accompanied by a database. The importance of such attribute table is given by the association of each entity representing a future to one or more descriptive information of any kinds, from strings to float numbers. Such attributes can then be used to query the database and solve some spatial analysis on site.
A shape file is public format for vector data. It consists of several files with same name but different extensions, among the others there are:

- .shp: mandatory file containing the geometry of entities, such as points, lines, polygons,
- .dbf: mandatory file containing the database, attributes associated to feature classes,
- .prj: auxiliary file containing the information related to the coordinate system projection,
- .xml: file containing auxiliary data descriptors, metadata.

*Road Network Infrastructures*
The precise representation of any types of networks is often obtained using a vector data, whether it is a shapefile or cad-file, because within for this format is possible to assign the flow direction attribute and store this information within the attribute table. A network is a system of interconnected elements such as edges and connecting joints which respectively correspond o lines and points. A transportation network representing a city road infrastructure contains the links, nodes and lines which provide potential routes to connect one point of interest to another. By using links feature within the network, it is possible to obtain lengths of roads, capacity, number of lanes, posted speed limits, free flow speed of roads, and many other information stored within the attribute table which may be useful to monitor and maintain a proper functioning of any mobility infrastructure. Through such implementation it results possible to identify different travel ways within a complex infrastructural system. It may be carried out a specific investigation identifying the best routes for vehicles movement, pedestrian itineraries and other kinds of flows.
As far as the data collection process, research target regarded the collection and isolation of data related to road ramification occurring for the cities under investigation in the area of concern.

*Administrative boundaries*
The data format used to describe city limits is also a shape file because boundaries are precisely represented by polylines or polygons and then it is automatically computed and stored the extension of such geometries. Moreover, by a join or relate operation on GIS software it can be appended an external table, for instance a *.csv* file, a *.xls* file or even a table from another shape file. Such appended tables enrich the basic geometrical representation with added quantitative and qualitative insights. For the case study of interest was append an internal database with a join process to the administrative boundaries shape file to then add information about total population for each territorial sub-division, percentage of population per gender, information regarding single barangays such as the city of origin and other data present stored within the external file. By managing and analysing data contained within the new database created by the join process, it may be retrieved extra data. In detail, for the case study it was calculated the density of population for each of the administrative subdivision of interest. These administrative boundaries were then used to identify traffic analysis zones to then initiate the route-finding analysis conducted on the base of the road network infrastructure.

### 3.4.4 Preliminary analysis

Before to enter the proposed idea of Digital Twin implementation derived by analysis performed on collected data just described on GIS software, were addressed some preliminary data management on ArcMap. In detail, were plotted two thematic maps as far as the population density of Metro Cebù territorial repartitions and the digital elevation model of the restricted zone under investigation.

*Population Density Map*
To start developing a map reporting all information concerning Metro Cebù population density, it was accessed the database promoted by *PhilGIS*, an entity which collects organizes and shares spatial georeferenced information about Philippine for educational and non-profit activities helping merge statistical analysis with spatial analysis.
From the downloadable products about the website, a generalized version of the Country administrative limits was retrieved and uploaded into the ArcMap software. Thus, it was imported the files regarding the Nation administrative boundaries for regions, provinces and towns of the Philippines Archipelago correlated by descriptive data. The administrative limits of the region of interest were manually selected and exported while the limits of other regions were discarded. These data were sufficient to plot an earlier working frame map of the area of interest but however without any information about population of the highly urbanized municipalities of Lapu-Lapu and Mandaue about which research is focused on. To access the demographic details, it was required to enter once again *PhilGIS* website and to download "*Population Demography*" shapefile. Once the file containing statistics about the population distribution according to census of 2015 evaluated for each municipality was obtained from the portal, it was loaded within ESRI application. Then, performing a "join by attribute" between the layered information about cities boundaries and population distribution, the software was capable to merge the two different repositories into a new database holding both information. By using the "Select by attribute" function, the two cities of interest have been extracted. By these means, it was possible to get the percentage of inhabitants with respect to the surface area covered by each municipality, precisely for Mandaue city and for Lapu-Lapu city.

To better represent the population on a map, it was plot a thematic representation based on percentage found to get an idea about the higher and lower population densities within the surrounding of the area. In *Figure 22*, as well as in *Map 1* included in the Appendix at the end of this paper, a topographical Base Map, from *ESRI Vector Basemaps*, was loaded from the directory in order to evidence the geography of Earth surface in particular for regions surrounding the site of interest.

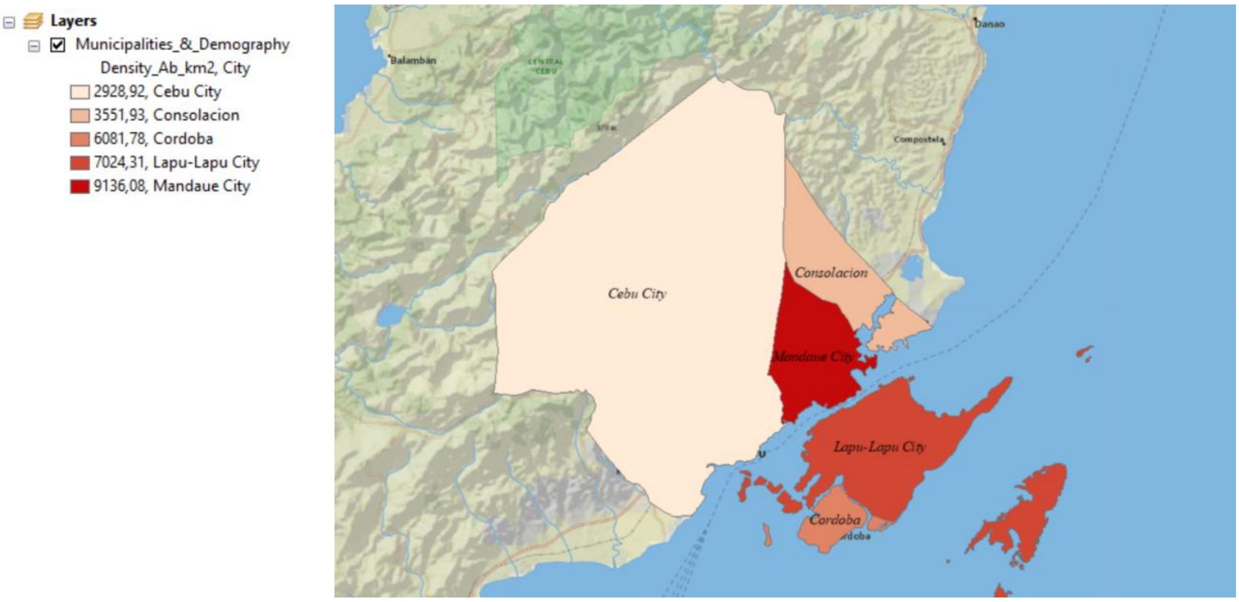



***Figure 22**: Population Density*

*DEM Map*

As far as the digital elevation model previously outlined, were downloaded two different datasets. Then, being the *MERIT Model* more exact than *NASA Model*, it was used as the base for a preliminary analysis on the elevation characteristics of the area about the site of interest. To this aim it was realized *Map 2* as follow.

From the portal of the University of Tokyo, required tiles were downloaded and added to the file on ArcMap software. Precisely, data was prepared as 5x5 degree tiles, corresponding to 6000pixel x 6000pixel. Having visualized the raster in ArcMap, it was clear as only two sections were overlapped with the area of concern. So, while the others were discarded, the remaining tiles were merged with the tools available in ArcToolbox "Mosaic to New Raster". The Mosaic tool allows to merge raster maps preserving the original datasets. Having obtained a single DEM, to reduce the computational time of file loading, the "Clip" geoprocessing tool was implemented to limit the information to a specific limited portion of investigation. The Clipping tool in general allows to cut a raster according to a section feature which, in this specific case, resulted being the cities around the Mactan Channel. Actually, to have a more general framework the site of interest was not limited to the Airport surrounding but it was extended to the city of Cebù, Consolacion and to the Municipality of Cordova.

The outcome of such procedure is shown in *Figure 23* and in the Appendix at the end of the present paper as *Map 2*. Such map geographically speaking describes a quite flat terrain, actually are depicted some peaks about 900 meters in Cebù City but however are beyond the core of the investigated zone. As a result of that, even if it was supposed to be used as base height of the site 3D mass model, for sake of computational efficiency the DEM was not exported in Arc Scene for the following extruding phase.

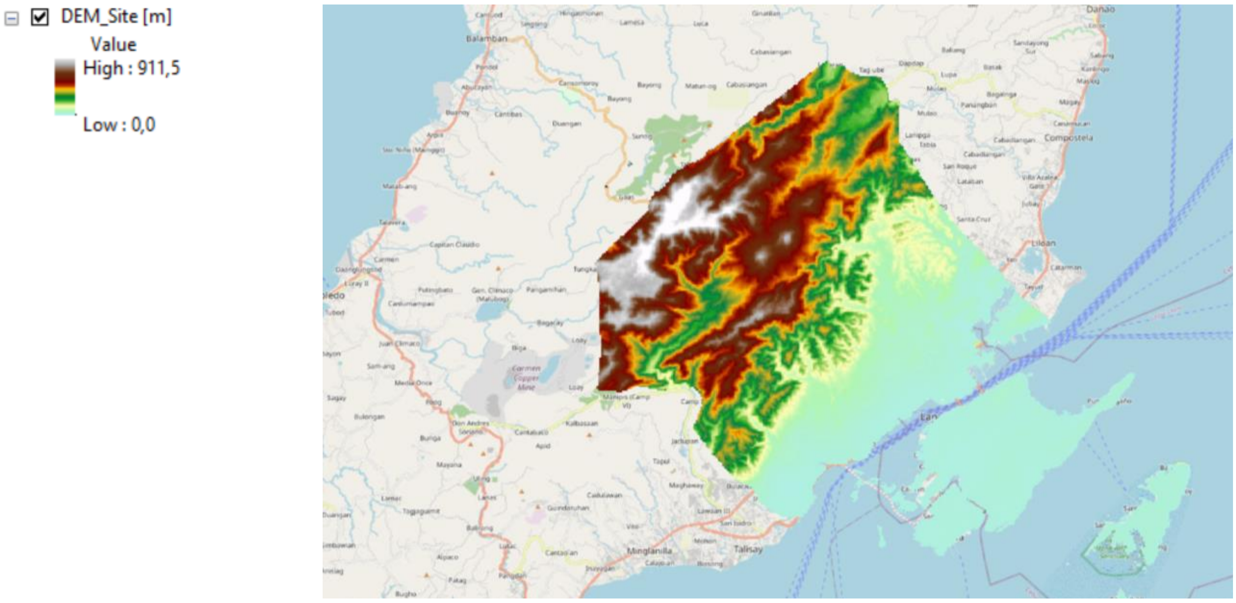



***Figure 23****: Digital Elevation Model*

### 3.4.5 Tools

As a premise of the present thesis paper, it was outlined the research multidisciplinary nature. Hereby, as far as tools used for the analysis of acquired data it must be distinguished between the different field of investigation of each graduating student. Within the present sub sub-chapter were introduced the main tools used for the civil-building part.
On such basis, major tools used for the civil-building applications were GIS, SWOT and BIM. For what concern the Geographical Information System, as already hinted in sub sub-chapter 3.4.4 "*Preliminary analysis*", it was adopted to perform some investigations of the study area and to construct a general working frame. Then, in sub-chapter 3.5 "*GIS Data modelling and analysis*" are described some more specific GIS usages about analysis carried out on ArcMap software in terms of route finding and traffic zone accessibility. Moreover, as a base for the successive Revit modelling phase, it was used the Arc Scene 3D visualization application, to realize a low-level model of the actual layout of the city. The present mass was the base for the detailed mobility Hub model but also for the wider master plan objective of the thesis. On the other hand, the S.W.O.T. tool was implemented to highlight endogenous and exogenous factors playing a role in Mactan urban mobility. Auxiliary tools are the macro trend analysis, which was realized on the base of the P.E.S.T.L.E. framework, and the risk matrix evaluation. Final aim of S.W.O.T. matrix was to support the planning of strategic actions and then the successive execution phase of the selected development plan which is overall presented at the end of sub sub-chapter 3.6.3 "*Decision-Making process*". The common point between GIS and BIM was the 3D mass model above mentioned. Using it as support it was modelled in Revit the smart mobility Hub which was then outlined in sub-chapter 3.8 "*BIM Data modelling*". The same ArcMap mass model was the base for the construction of the virtual reality scene beauty which is the goal of M. Fanshu and Z. Zheyuan thesis work. To this objective the Hub template was exported in "*fbx*" format to finally construct the interactive scene showing the idea of Digital Twin proposed by the multidisciplinary team working on the present research.

## 3.5 GIS Data modelling and analysis

Within sub sub-chapter 3.4.4, some preliminary analysis conducted on the base of collected spatial data were described. On the other hand, in the present sub-chapter is presented the methodology of more specific analysis about mobility in the site of interest. Precisely, it is addressed the construction of city road network and the definition of traffic analysis zone for the route-finding analysis in normal and constrained traffic scenarios. At last, the accessibility analysis about TAZs having assumed as a main point of interest the International Airport of Mactan which is the principal urban mobility node of the entire Island. The base for all analysis just hinted is the creation of the complex city infrastructural system on a GIS platform, which constructing procedure is now illustrated.

### 3.5.1 Road Network Creation

A road network definition was given within sub sub-chapter 3.4.3 "*Vector Data: Road network & Administrative boundaries*" as the representation of a city road infrastructure having the links, nodes and lines which provide potential routes to connect one site of interest to another. Moreover, in the same paragraph it was suggested an implementation of such network consisting in the identification of best different travel ways within a complex system. That is the point of the present analysis, so finding best routes for vehicles movements within the urban environment assuming different boundary conditions.
The road network creation starts by the download of the "*Roads*" shapefile by *PhilGIS* website. Once added these data to the pre-defined layers, the file was ready to be cleaned from all useless information. First, by taking advantage of already existing geometries about cities in the surrounding of Mactan Channel, it was implemented the "Clip" tool, in the Geoprocessing window, to extract in a new shapefile only roads crossing municipalities of interest, so Mandaue and Lapu-Lapu. After that, the file was further edited. Since the following analysis will be based on cars and motor vehicles, were removed all streets not traversable by car but only by pedestrians, such as for instance footpaths. Moving onwards, by referring to the functional classification provided by the Philippine Official Department of Public Works and Highways [73], the street subdivision and related speed limitations presented in *Table 4* were considered. For what concern speed limits of each and every road category, and the different classification observed between T*able 4* and the "*Roads*" shapefile downloaded by *PhilGIS*, the following assumptions were adopted to be coherent during the route-finding analysis:

- Expressway: Highway with interchanges, whose maximum speed limit is 100 km/h. However, expressways are not present within the case study area,
- National Road: Street which directly connects major cities. This category includes "*primary roads*" whose maximum speed was 80 km/h then lowered to 60 km/h on bridges,
- Provincial Road: Connects cities and municipalities without traversing National roads, alternatively it connects National roads to barangays through rural areas. This category includes "*secondary roads*", "*tertiary roads*" and roads labelled in the file as "*UnClassified*". The maximum speed limit in this case was fixed at 40 km/h,

- Municipal and City Road: Road connecting Provincial and National roads but also a street which provide inter-barangay connections to major Municipal. This category includes "*residential roads*" and "*service roads*" whose maximum speed was fixed at 30 km/h.

Speed limitations for Provincial and Municipal roads were further lowered to a maximum of 20 km/h to account for the overcrowding of streets in zones where drivers must pass quite stationary. Moreover, lower speed limits just introduced are justified by the high percentage of unpaved roads in the Country, not safe for high flow of vehicles, which is close to the 46% in which the greater share belongs to inter-barangay roads.

**Current Classification System**

**(Per D.O. No. 133, s. 2018)**

| | |
|---|---|
| **National Primary Roads** | • **A contiguous length of significant road sections extending linearly without any breaks or forks that connect major cities (at least around 100,000 population) comprising the main trunk line or the backbone of the national road system.** |
| **National Secondary Roads** | • **Directly connect cities to National Primary Roads, except in metropolitan areas**<br>• **Directly connect major ports and ferry terminals (as defined by DOTr) to National Primary Roads**<br>• **Directly connect major airports (as defined by DOTr) to National Primary Roads**<br>• **Directly connect tourist service centers (as defined by DOT) to National Primary Roads or other National Secondary Roads**<br>• **Directly connect cities (not included in the category of major cities)**<br>• **Directly connect provincial capitals within the same region**<br>• **Directly connect major National Government Infrastructure to National Primary Roads or other National Secondary Roads** |
| **Applicable only for Primary and Secondary Roads** | • **Bypass/Diversion Roads – Roads that divert through traffic away from the city/municipality business centers (with affirmative feasibility study)** |
| | • **Roads that would connect or fill the gap between adjoining national roads (protruding) to form a continuous national road network.** |
| **National Tertiary Roads** | • **Other existing roads under DPWH which perform a local function** |
| **Provincial Roads** | • **Connect cities and municipalities without traversing National Roads**<br>• **Connect to National Roads to barangays through rural areas**<br>• **Connect to major provincial government infrastructure** |
| **Municipal and City Roads** | • **Roads within a Poblacion**<br>• **Roads that connect to Provincial and National Roads**<br>• **Roads that provide inter-barangay connections to major Municipal and City Infrastructure without traversing Provincial Roads** |
| **Barangay Roads** | • **Other Public Roads (officially turned over) within the barangay and not covered in the above definitions** |
| **Expressways** | • **Highways with limited access, normally with interchanges; may include facilities for levying tolls for passage in an open or closed system.** |

***Table 4***: *National Road classification*

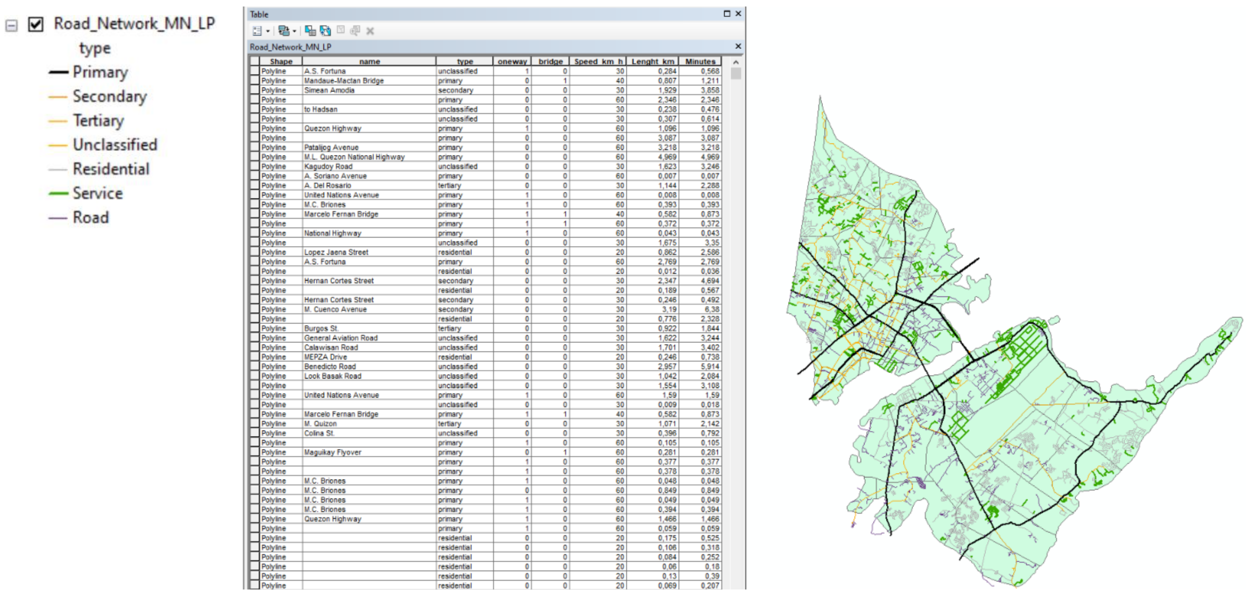
Source: Department of Public Works and Highways. Philippine National Road Network. (2019)

So far, the only cost attribute present within the "*Road*" file database was the travel length. Since the aim is to investigate also quickest routes occurring between two zones, in terms of travel time, the time cost attribute was to be estimated and recorded within the attribute table. The estimation of time is based on the speed limitations in force, abovementioned, and the road functional classification described within *Table 4*. By computing the speed in m/s, generating a new field within the attribute table, speed m/s, and associating to each class the corresponding velocity limitation, it was then possible to perform the time evaluation assuming minutes of travelling. The computation was performed directly onto the attribute table by accessing the "field calculator" option and imposing the following relation:

$$Time = \frac{Lenght}{Speed * 60}\ [minutes]$$

Having identified the road distribution in the site of interest and having organized the "*Road*" database with all attributes necessary for the next analysis, the network was ready to be generated. By opening the ArcCatalog and by selecting the shape file of interest, which was "*Road_Network_MN_LP*", it was possible to turn the model into a network. By going through a set of requests, finally the network based on two different cost attributes, length and travel time, was visualized through Arc Map interface.

In *Figure 24*, and within the Appendix as *Map 3*, is plot the final road network subdivided by speed limits on the base of road functional classification provided in *Table 4*. Moreover, in *Figure 24* is shown the database, or attribute table, including all road attributes such as the street name, road type, one-way, bridge, speed limits, roads length in kms and travel time in minutes. The network is the starting point for the next phase of route-finding and optimization but is also the key for the final accessibility analysis of barangay administrative subdivision of the two municipalities under investigation.




| Shape | name | type | oneway | bridge | Speed km h | Lenght km | Minutes |
|---|---|---|---|---|---|---|---|
| Polyline | A.S. Fortuna | unclassified | 1 | 0 | 30 | 0,284 | 0,568 |
| Polyline | Mandaue-Mactan Bridge | primary | 0 | 1 | 40 | 0,807 | 1,211 |
| Polyline | Simean Amodia | secondary | 0 | 0 | 30 | 1,929 | 3,858 |
| Polyline | | primary | 0 | 0 | 60 | 2,346 | 2,346 |
| Polyline | to Hadsan | unclassified | 0 | 0 | 30 | 0,238 | 0,476 |
| Polyline | | unclassified | 0 | 0 | 30 | 0,307 | 0,614 |
| Polyline | Quezon Highway | primary | 1 | 0 | 60 | 1,096 | 1,096 |
| Polyline | | primary | 0 | 0 | 60 | 3,087 | 3,087 |
| Polyline | Pataljog Avenue | primary | 0 | 0 | 60 | 3,218 | 3,218 |
| Polyline | M.L. Quezon National Highway | primary | 0 | 0 | 60 | 4,969 | 4,969 |
| Polyline | Kagudoy Road | unclassified | 0 | 0 | 30 | 1,623 | 3,246 |
| Polyline | A. Soriano Avenue | primary | 0 | 0 | 60 | 0,007 | 0,007 |
| Polyline | A. Del Rosario | tertiary | 0 | 0 | 30 | 1,144 | 2,288 |
| Polyline | United Nations Avenue | primary | 1 | 0 | 60 | 0,008 | 0,008 |
| Polyline | M.C. Briones | primary | 1 | 0 | 60 | 0,393 | 0,393 |
| Polyline | Marcelo Fernan Bridge | primary | 1 | 1 | 40 | 0,582 | 0,873 |
| Polyline | | primary | 1 | 1 | 60 | 0,372 | 0,372 |
| Polyline | National Highway | primary | 1 | 0 | 60 | 0,043 | 0,043 |
| Polyline | | unclassified | 0 | 0 | 30 | 1,675 | 3,35 |
| Polyline | Lopez Jaena Street | residential | 0 | 0 | 20 | 0,862 | 2,586 |
| Polyline | A.S. Fortuna | primary | 0 | 0 | 60 | 2,769 | 2,769 |
| Polyline | | residential | 0 | 0 | 20 | 0,012 | 0,036 |
| Polyline | Hernan Cortes Street | secondary | 0 | 0 | 30 | 2,347 | 4,694 |
| Polyline | | residential | 0 | 0 | 20 | 0,189 | 0,567 |
| Polyline | Hernan Cortes Street | secondary | 0 | 0 | 30 | 0,246 | 0,492 |
| Polyline | M. Cuenco Avenue | secondary | 0 | 0 | 30 | 3,19 | 6,38 |
| Polyline | | residential | 0 | 0 | 20 | 0,776 | 2,328 |
| Polyline | Burgos St. | tertiary | 0 | 0 | 30 | 0,922 | 1,844 |
| Polyline | General Aviation Road | unclassified | 0 | 0 | 30 | 1,622 | 3,244 |
| Polyline | Calawisan Road | unclassified | 0 | 0 | 30 | 1,701 | 3,402 |
| Polyline | MEPZA Drive | residential | 0 | 0 | 20 | 0,246 | 0,738 |
| Polyline | Benedicto Road | unclassified | 0 | 0 | 30 | 2,957 | 5,914 |
| Polyline | Look Basak Road | unclassified | 0 | 0 | 30 | 1,042 | 2,084 |
| Polyline | | unclassified | 0 | 0 | 30 | 1,554 | 3,108 |
| Polyline | United Nations Avenue | primary | 1 | 0 | 60 | 1,59 | 1,59 |
| Polyline | | unclassified | 0 | 0 | 30 | 0,009 | 0,018 |
| Polyline | Marcelo Fernan Bridge | primary | 1 | 1 | 40 | 0,582 | 0,873 |
| Polyline | M. Quizon | tertiary | 0 | 0 | 30 | 1,071 | 2,142 |
| Polyline | Colina St. | unclassified | 0 | 0 | 30 | 0,396 | 0,792 |
| Polyline | | primary | 1 | 0 | 60 | 0,105 | 0,105 |
| Polyline | Maguikay Flyover | primary | 0 | 1 | 60 | 0,281 | 0,281 |
| Polyline | | primary | 1 | 0 | 60 | 0,377 | 0,377 |
| Polyline | | primary | 1 | 0 | 60 | 0,378 | 0,378 |
| Polyline | M.C. Briones | primary | 1 | 0 | 60 | 0,048 | 0,048 |
| Polyline | M.C. Briones | primary | 0 | 0 | 60 | 0,849 | 0,849 |
| Polyline | M.C. Briones | primary | 1 | 0 | 60 | 0,049 | 0,049 |
| Polyline | M.C. Briones | primary | 1 | 0 | 60 | 0,394 | 0,394 |
| Polyline | Quezon Highway | primary | 1 | 0 | 60 | 1,466 | 1,466 |
| Polyline | | primary | 1 | 0 | 60 | 0,059 | 0,059 |
| Polyline | | residential | 0 | 0 | 20 | 0,175 | 0,525 |
| Polyline | | residential | 0 | 0 | 20 | 0,106 | 0,318 |
| Polyline | | residential | 0 | 0 | 20 | 0,084 | 0,252 |
| Polyline | | residential | 0 | 0 | 20 | 0,06 | 0,18 |
| Polyline | | residential | 0 | 0 | 20 | 0,13 | 0,39 |
| Polyline | | residential | 0 | 0 | 20 | 0,069 | 0,207 |

***Figure 24***: *Road Network & Attribute table*

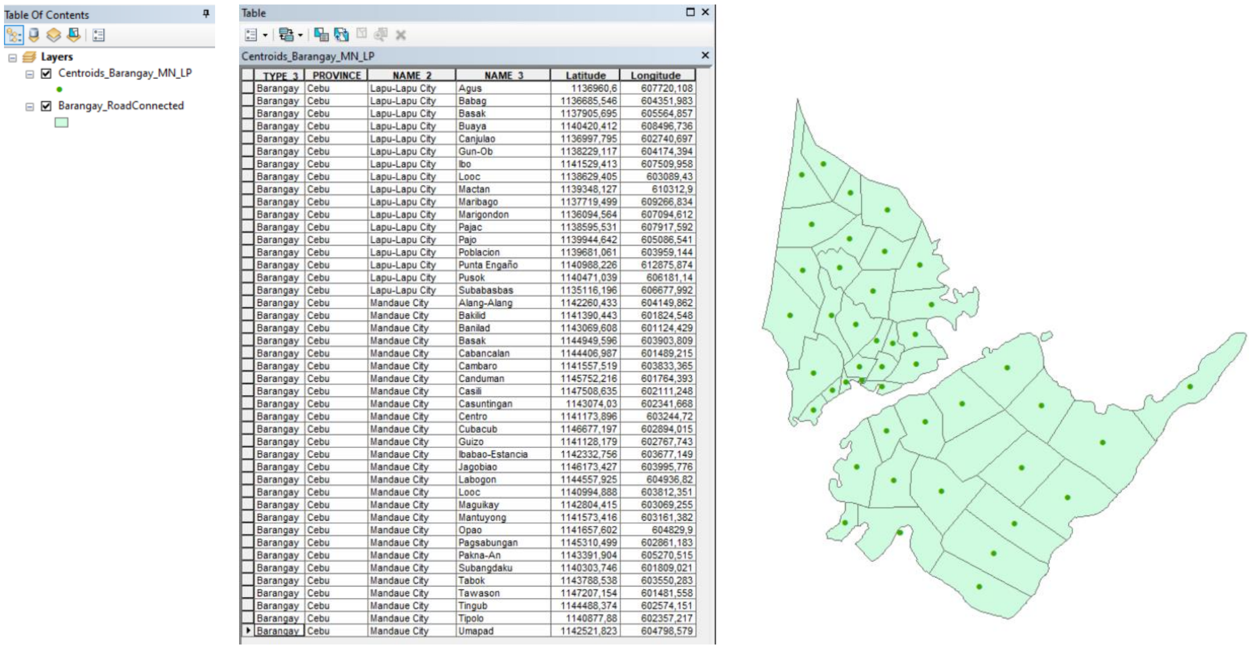
### 3.5.2 Route-finding analysis

Having prepared the working field within ArcMap interface, meaning the road network in *Figure 24*, the analysis was ready to start. The investigation of the road infrastructure to find best route connections should take into account any kind of attribute presents, so road types, paths length, speed limits and even the travel time cost attribute indirectly computed. In general, using a route analysis we may, for example, specify the shortest path occurring among different stops when going to work, or instead it could be possible to find the quickest pattern when travelling. These common daily actions often see the implementation of these computations through navigator but, perhaps, also when working with ArcMap some simulations of this kind may be developed and implemented. For instance, this may improve the logistical organization of a city's road infrastructure or moreover help performing an efficient and strategic decision-making process, as it is for this case study.

*Traffic Analysis Zones repartition*
In order to perform the route-finding analysis, it is first required to simplify the area of interest by introducing the concept of Traffic Analysis Zones. The use of TAZs is a matter of necessity, because, even if it could be possible to know where precisely a trip starts from and ends, such trips for sake of computational efficiency are aggregated in the centroids of traffic zones.
To confine the following accessibility analysis strictly to the site objective of the research, it was necessary to focus on the administrative boundaries of Mandaue city and Lapu-Lapu city. Therefore, on the base of administrative barangay subdivision outlined by a shapefile downloadable from the *PhilGIS* website, it was executed an adequate repartition of the two cities. On such assumptions, it was decided to limit the zones of analysis to nearly 44 TAZs including:

- 17 barangays of Lapu-Lapu city on the island of Mactan.
- 27 barangays of Mandaue city on the main Cebù Island.

Based on the identified clipped area, it was necessary to identify the centroids of the zones of concern. By associating the adequate projected reference system WGS 1894 UTM Zone 51N and reporting the respective latitude and longitude coordinates, a database file named "*Centroids_Barangay_MN_LP*" was produced to finally display the centroid of each barangay. After having subdivided the territory in traffic analysis zones and found for each repartition the centroid, were defined the set of origin and destination points for road connections. According to reasonings made so far about the site, the International Airport, being the place attracting the majority of trips in the entire Island, was selected as the destination point of all traffic simulations, while the centroid of each and every barangay was defined as the origin point of single trips. For sake of simplicity, since the analysis were based on travelling by engine vehicles were discarded all barangays resulted being not road connected. In *Map 4* included within the Appendix are shown the barangays, with the related centroid, considered for the best route-finding analysis. Moreover, it is described the International Airport coordinates obtained by the file "*Airport_Location*" provided by *PhilGIS* website. Same results in terms of latitude and longitude barangays coordinates are presented in *Figure 25*.




| TYPE_3 | PROVINCE | NAME_2 | NAME_3 | Latitude | Longitude |
|---|---|---|---|---|---|
| Barangay | Cebu | Lapu-Lapu City | Agus | 1136960,6 | 607720,108 |
| Barangay | Cebu | Lapu-Lapu City | Babag | 1136685,546 | 604351,983 |
| Barangay | Cebu | Lapu-Lapu City | Basak | 1137905,695 | 605564,857 |
| Barangay | Cebu | Lapu-Lapu City | Buaya | 1140420,412 | 608496,736 |
| Barangay | Cebu | Lapu-Lapu City | Canjulao | 1136997,795 | 602740,697 |
| Barangay | Cebu | Lapu-Lapu City | Gun-Ob | 1138229,117 | 604174,394 |
| Barangay | Cebu | Lapu-Lapu City | Ibo | 1141529,413 | 607509,958 |
| Barangay | Cebu | Lapu-Lapu City | Looc | 1138629,405 | 603089,43 |
| Barangay | Cebu | Lapu-Lapu City | Mactan | 1139348,127 | 610312,9 |
| Barangay | Cebu | Lapu-Lapu City | Maribago | 1137719,499 | 609266,834 |
| Barangay | Cebu | Lapu-Lapu City | Marigondon | 1136094,564 | 607094,612 |
| Barangay | Cebu | Lapu-Lapu City | Pajac | 1138595,531 | 607917,592 |
| Barangay | Cebu | Lapu-Lapu City | Pajo | 1139944,642 | 605086,541 |
| Barangay | Cebu | Lapu-Lapu City | Poblacion | 1139681,061 | 603959,144 |
| Barangay | Cebu | Lapu-Lapu City | Punta Engaño | 1140988,226 | 612875,874 |
| Barangay | Cebu | Lapu-Lapu City | Pusok | 1140471,039 | 606181,14 |
| Barangay | Cebu | Lapu-Lapu City | Subabasbas | 1135116,196 | 606677,992 |
| Barangay | Cebu | Mandaue City | Alang-Alang | 1142260,433 | 604149,862 |
| Barangay | Cebu | Mandaue City | Bakilid | 1141390,443 | 601824,548 |
| Barangay | Cebu | Mandaue City | Banilad | 1143069,608 | 601124,429 |
| Barangay | Cebu | Mandaue City | Basak | 1144949,596 | 603903,809 |
| Barangay | Cebu | Mandaue City | Cabancalan | 1144406,987 | 601489,215 |
| Barangay | Cebu | Mandaue City | Cambaro | 1141557,519 | 603833,365 |
| Barangay | Cebu | Mandaue City | Canduman | 1145752,216 | 601764,393 |
| Barangay | Cebu | Mandaue City | Casili | 1147508,635 | 602111,248 |
| Barangay | Cebu | Mandaue City | Casuntingan | 1143074,03 | 602341,668 |
| Barangay | Cebu | Mandaue City | Centro | 1141173,896 | 603244,72 |
| Barangay | Cebu | Mandaue City | Cubacub | 1146677,197 | 602894,015 |
| Barangay | Cebu | Mandaue City | Guizo | 1141128,179 | 602767,743 |
| Barangay | Cebu | Mandaue City | Ibabao-Estancia | 1142332,756 | 603677,149 |
| Barangay | Cebu | Mandaue City | Jagobiao | 1146173,427 | 603995,776 |
| Barangay | Cebu | Mandaue City | Labogon | 1144557,925 | 604936,82 |
| Barangay | Cebu | Mandaue City | Looc | 1140994,888 | 603812,351 |
| Barangay | Cebu | Mandaue City | Maguikay | 1142804,415 | 603069,255 |
| Barangay | Cebu | Mandaue City | Mantuyong | 1141573,416 | 603161,382 |
| Barangay | Cebu | Mandaue City | Opao | 1141657,602 | 604829,9 |
| Barangay | Cebu | Mandaue City | Pagsabungan | 1145310,499 | 602861,183 |
| Barangay | Cebu | Mandaue City | Pakna-An | 1143391,904 | 605270,515 |
| Barangay | Cebu | Mandaue City | Subangdaku | 1140303,746 | 601809,021 |
| Barangay | Cebu | Mandaue City | Tabok | 1143788,538 | 603550,283 |
| Barangay | Cebu | Mandaue City | Tawason | 1147207,154 | 601481,558 |
| Barangay | Cebu | Mandaue City | Tingub | 1144488,374 | 602574,151 |
| Barangay | Cebu | Mandaue City | Tipolo | 1140877,88 | 602357,217 |
| Barangay | Cebu | Mandaue City | Umapad | 1142521,823 | 604798,579 |

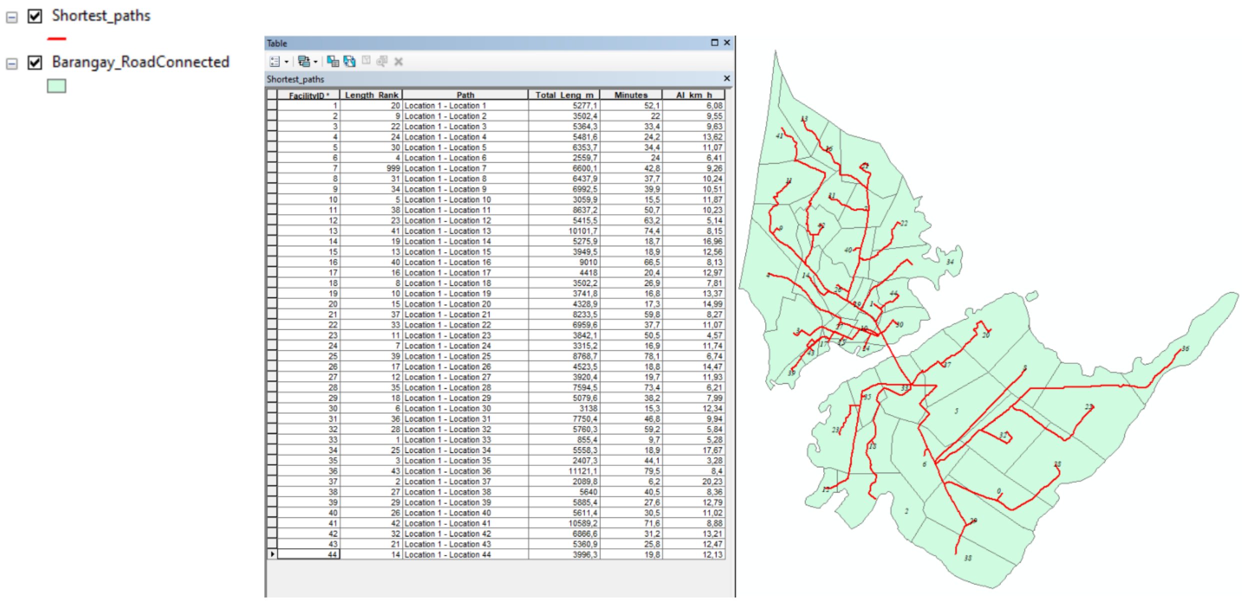
***Figure 25**: Traffic Analysis Zones and Barangay repartition*

*Network Analyst: closest facility*

In order to at last trace the accessibility of different barangays present on the territory, whereby accessibility means the evaluation of the effectiveness of transport policy measures on a study area modelling both travel demand and interactions among transportation system and land use, the "Closest Facility" approach was considered. Closest facility is a "Network Analyst" option which quantifies the cost of travelling between origins and destinations establishing the closest one another. This approach displays the best routes between selected points on the base of the impedances immitted, travel time or length, and reports the respective driving directions. As a major difference with respect the "OD cost matrix solver", the analysis is performed slowly but it is more proximate to reality because software returns the real shape of suggested pattern.

Two different analysis were performed aiming to find the best routes in terms of length and time to connect the Airport to each and every Barangay of Lapu-Lapu city, Mandaue city and vice versa. However, since the city of Mandaue is placed on the other side of Mactan Channel, the investigation was focused mainly on these itineraries because they are influenced by the level of traffic on bridges. The different analysis considered aim to minimize the two network cost attributes created. Hereby, the first analysis includes finding the best way in terms of minimum travel distance, while the second is devoted to identifying best courses in terms of minimum travel time. The whole of journey found by the "Network Analyst" tool were plotted and are shown within *Map 5*, *Map 6* and *Map 7* in the Appendix at the end of the thesis paper. Precisely, in *Map 5* are shown shortest itineraries, in *Map 6* is shown the comparison between the two solutions found according to the different cost attribute assigned for the analysis, and last in *Map 7* are reported quickest routes found by the "Network Analyst" tool. For sake of completeness in *Figure 26* is described the shortest paths solution together with the attribute table. The database associated to roads in output includes the total travel length and the total travel time observed for each connection. Moreover, the attribute table includes the AI index expressed in km/h which, once plotted in a choropleth map, allows to observe the accessibility of each and every barangay in the area under investigation.

The solution displayed in *Figure 26* is optimized in terms of travel length, the cost attribute set as the impedance of the analysis. The "Length Rank" attribute is a field automatically generated by the Network Analyst tool to show the itineraries rank in terms of cost attribute implemented, in this case the length. It must be though highlighted the peculiarity of shortest solution in *Figure 26*. Indeed, travelling from the Airport to Mandaue city ideally drivers to reduce travel length should not cross the Marcelo-Fernan Bridge located in the North of the Island. Since from the site characterization analysis discussed in sub sub-chapter 3.3.2 "*Mactan mobility*" the Osmeña bridge, the one more southern in the Island, resulted being the busiest one, "Network Analyst" results partially confirm real habits of people, who prefer travelling on it than the Marcelo Fernan Bridge.




| FacilityID * | Length Rank | Path | Total Leng m | Minutes | Al km h |
|---|---|---|---|---|---|
| 1 | 20 | Location 1 - Location 1 | 5277,1 | 52,1 | 6,08 |
| 2 | 9 | Location 1 - Location 2 | 3502,4 | 22 | 9,55 |
| 3 | 22 | Location 1 - Location 3 | 5364,3 | 33,4 | 9,63 |
| 4 | 24 | Location 1 - Location 4 | 5481,6 | 24,2 | 13,62 |
| 5 | 30 | Location 1 - Location 5 | 6353,7 | 34,4 | 11,07 |
| 6 | 4 | Location 1 - Location 6 | 2559,7 | 24 | 6,41 |
| 7 | 999 | Location 1 - Location 7 | 6600,1 | 42,8 | 9,26 |
| 8 | 31 | Location 1 - Location 8 | 6437,9 | 37,7 | 10,24 |
| 9 | 34 | Location 1 - Location 9 | 6992,5 | 39,9 | 10,51 |
| 10 | 5 | Location 1 - Location 10 | 3059,9 | 15,5 | 11,87 |
| 11 | 38 | Location 1 - Location 11 | 8637,2 | 50,7 | 10,23 |
| 12 | 23 | Location 1 - Location 12 | 5415,5 | 63,2 | 5,14 |
| 13 | 41 | Location 1 - Location 13 | 10101,7 | 74,4 | 8,15 |
| 14 | 19 | Location 1 - Location 14 | 5275,9 | 18,7 | 16,96 |
| 15 | 13 | Location 1 - Location 15 | 3949,5 | 18,9 | 12,56 |
| 16 | 40 | Location 1 - Location 16 | 9010 | 66,5 | 8,13 |
| 17 | 16 | Location 1 - Location 17 | 4418 | 20,4 | 12,97 |
| 18 | 8 | Location 1 - Location 18 | 3502,2 | 26,9 | 7,81 |
| 19 | 10 | Location 1 - Location 19 | 3741,8 | 16,8 | 13,37 |
| 20 | 15 | Location 1 - Location 20 | 4328,9 | 17,3 | 14,99 |
| 21 | 37 | Location 1 - Location 21 | 8233,5 | 59,8 | 8,27 |
| 22 | 33 | Location 1 - Location 22 | 6959,6 | 37,7 | 11,07 |
| 23 | 11 | Location 1 - Location 23 | 3842,1 | 50,5 | 4,57 |
| 24 | 7 | Location 1 - Location 24 | 3315,2 | 16,9 | 11,74 |
| 25 | 39 | Location 1 - Location 25 | 8768,7 | 78,1 | 6,74 |
| 26 | 17 | Location 1 - Location 26 | 4523,5 | 18,8 | 14,47 |
| 27 | 12 | Location 1 - Location 27 | 3920,4 | 19,7 | 11,93 |
| 28 | 35 | Location 1 - Location 28 | 7594,5 | 73,4 | 6,21 |
| 29 | 18 | Location 1 - Location 29 | 5079,6 | 38,2 | 7,99 |
| 30 | 6 | Location 1 - Location 30 | 3138 | 15,3 | 12,34 |
| 31 | 36 | Location 1 - Location 31 | 7750,4 | 46,8 | 9,94 |
| 32 | 28 | Location 1 - Location 32 | 5760,3 | 59,2 | 5,84 |
| 33 | 1 | Location 1 - Location 33 | 855,4 | 9,7 | 5,28 |
| 34 | 25 | Location 1 - Location 34 | 5558,3 | 18,9 | 17,67 |
| 35 | 3 | Location 1 - Location 35 | 2407,3 | 44,1 | 3,28 |
| 36 | 43 | Location 1 - Location 36 | 11121,1 | 79,5 | 8,4 |
| 37 | 2 | Location 1 - Location 37 | 2089,8 | 6,2 | 20,23 |
| 38 | 27 | Location 1 - Location 38 | 5640 | 40,5 | 8,36 |
| 39 | 29 | Location 1 - Location 39 | 5885,4 | 27,6 | 12,79 |
| 40 | 26 | Location 1 - Location 40 | 5611,4 | 30,5 | 11,02 |
| 41 | 42 | Location 1 - Location 41 | 10589,2 | 71,6 | 8,88 |
| 42 | 32 | Location 1 - Location 42 | 6866,6 | 31,2 | 13,21 |
| 43 | 21 | Location 1 - Location 43 | 5360,9 | 25,8 | 12,47 |
| 44 | 14 | Location 1 - Location 44 | 3996,3 | 19,8 | 12,13 |

***Figure 26****: Network Analyst: Shortest itineraries*

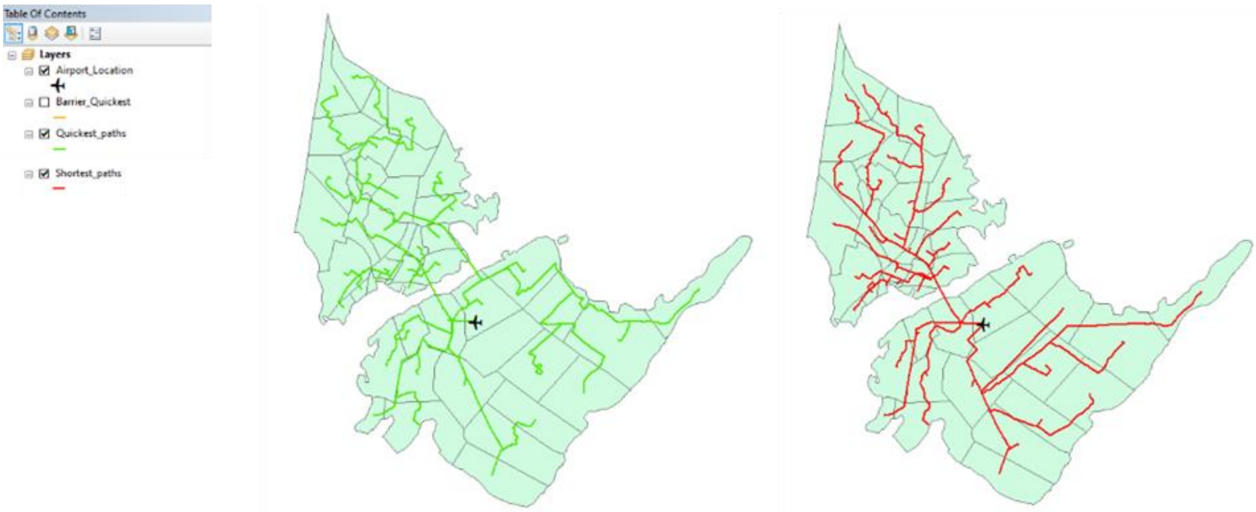



***Figure 27****: Network Analyst: Comparison among shortest and quickest itineraries*

On the other hand, the comparison between shortest and quickest solution provided by the "Network Analyst" tool implementation is shown in *Figure 27*. From the figure may be observed the different itineraries a driver should follow, either in case it aims to reduce the travel time or the travel length, to reach the desired Barangay from the International Airport or vice versa. The itinerary variations depicted in the two different analysis conducted by "Network Analyst" tool is more evident in *Map 6*, in the Appendix of the thesis paper, where travel paths suggested by ArcMap are overlaid one another.

### 3.5.3 Accessibility analysis

The assessment of outcomes derived by the implementation of "Network Analyst" tool is based on the concept of accessibility and the corresponding maps. The accessibility map is a choropleth representation in which coloured areas describe the effectiveness of reaching destinations or activities in the corresponding study environment, as could be a city or a country. As it was mentioned at the beginning of sub-chapter 3.6 "*GIS Data modelling and analysis*", an accessibility analysis is generally associated with a place of origin and is seen as a measure of the ease of reaching and interacting with destinations.
In the case study under investigation origin and destinations are respectively the Airport of Mactan and local Barangays. A measure of accessibility may be given in terms of Accessibility Index, AI, that is the speed computed as the ratio between the minimum distance to connect two zones and the minimum travel time among the same two areas [74]:

$$\mathbf{Acc_{i,j}} = \frac{\mathbf{dist_{i,j}}}{\mathbf{time_{i,j}}}$$

Where:

- $Dist_{i,\,j}$= minimum distance between the two zones (commonly centroids),
- $Time_{i,j}$= minimum travel time between the two zones (commonly centroids),
- i= trip origin,
- j = trip destination.

Considering *Figure 26* reporting the comparison between itineraries found according to travel length impedance and routes resulted by the minimization of travel time, solution depicted by "Network Analyst" tool are different despite of the common way starting point, which is the centroid of single barangays. As a result of that, different routes result into different accessibility index for the same urban zone considered. To show these differences in terms of accessibility, accessibility indices obtained by the implemented analytical tool must be plotted into some adequate maps. To this aim, it was required to save and export from ArcMap software a database file for each of the two closest facility road solutions identified. Having exported such "*dbf*" format file, then it was possible to compute the AIs for each depicted route. Hereby, computing for 44 found patterns the associated travel speed in terms of accessibility index, it was assigned an alphanumerical code for each which allowed to then perform a "join by attribute" process with the layer "*Barangay_Road_Connected*". After AI computations it was possible to address the related accessibility maps which results are shown in in *Figure 28,* for what concern the travel length impedance, and in *Figure 29* for the travel time cost attribute. Same maps are reported in the Appendix, respectively labelled as *Map 8,* for shortest itineraries, and *Map 9* for quickest routes.

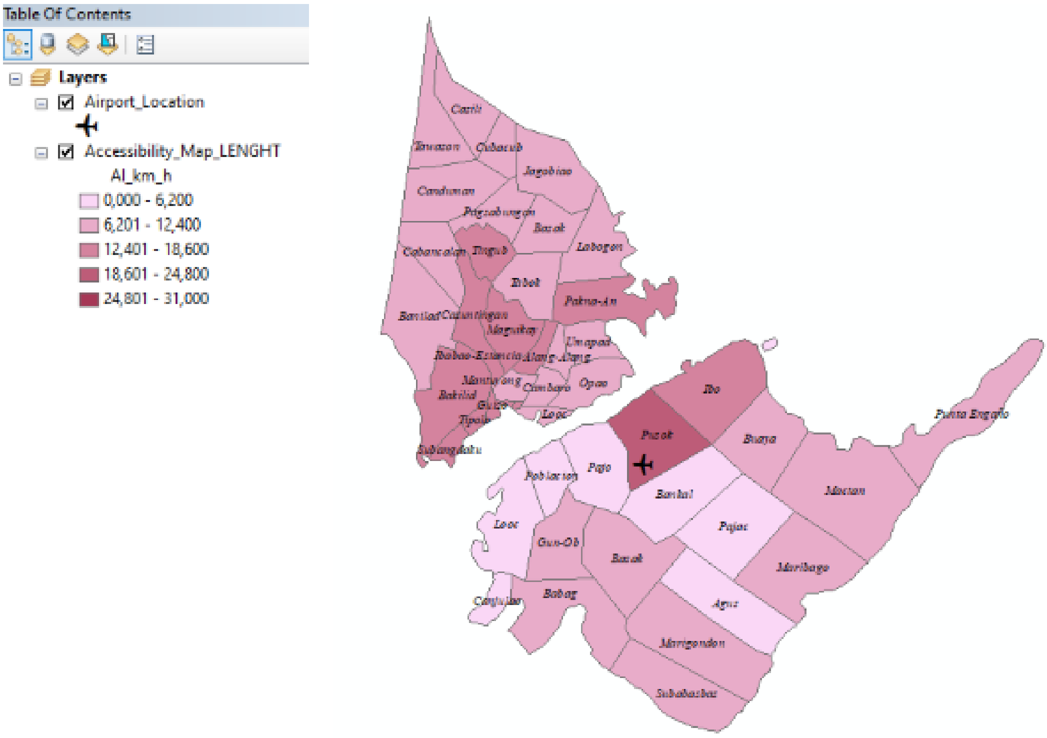



***Figure 28**: Accessibility analysis: Map by Travel length*

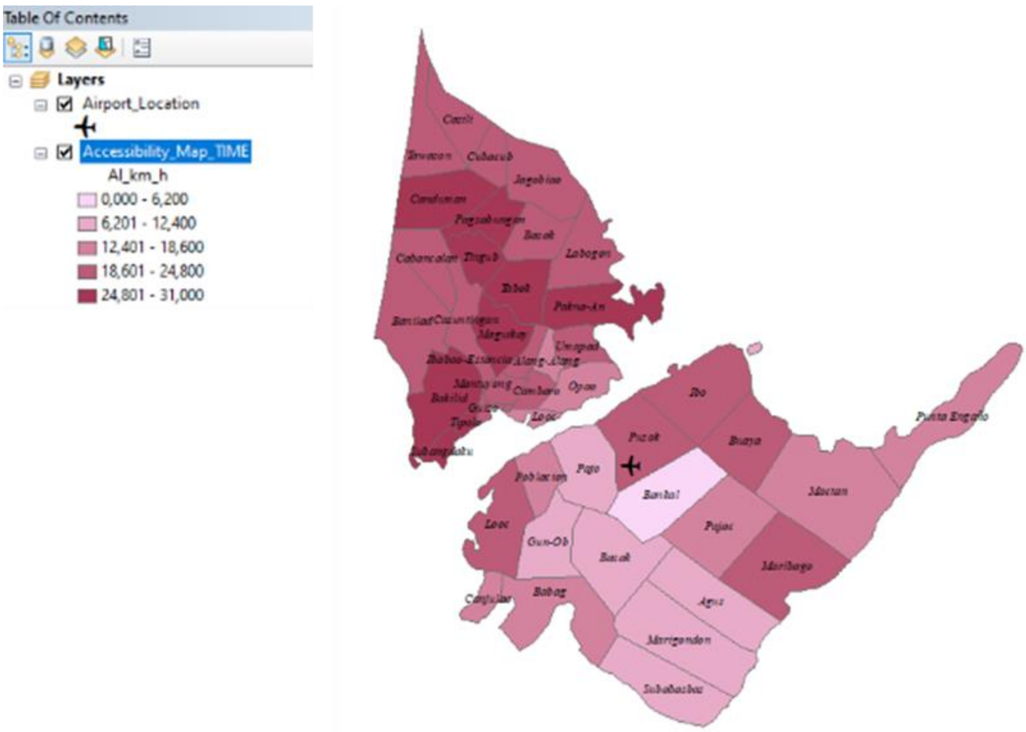


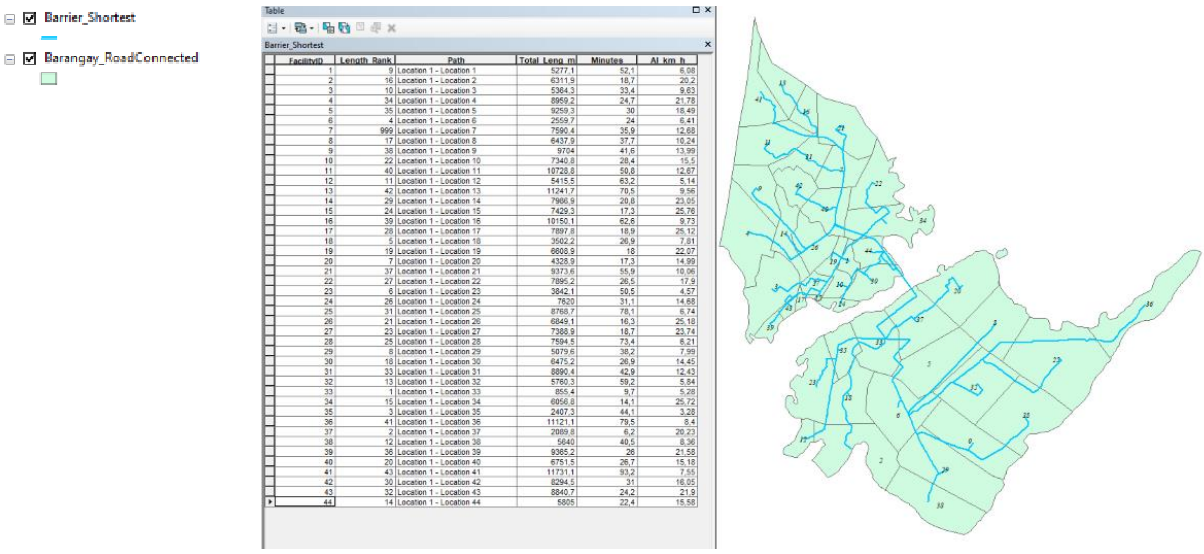

***Figure 29**: Accessibility analysis: Map by Travel time*

Outputs given in *Figure 28* and *Figure 29* present some significant differences. By comparing these two maps and by picking two same areas, generally the higher accessibility index is obtained for the time-optimized solution suggested in *Figure 28*. Indeed, since the study area is small, the travel length between one or another way does not change significantly but the time does. In detail, in one case drivers travel on primary roads characterized by multi-lanes in a good state of maintenance and with speed limits up to 80 km/h, while in the other case because of the length impedance constraint drivers are obliged to cross slightly shorter roads but in poor state of maintenance and with lower speed limits, sometimes equal to 20 km/h. For sake of clarity, since barangay "*Bankal*" is the place in which is placed the International Airport of Mactan, the corresponding Accessibility Index was imposed equal to 0,00 km/h, so in both maps it results in a lighter pink colour.

*Constrained traffic conditions*

The outcomes of the analysis just performed, and the related accessibility maps clearly describe the S. Osmeña Bridge as the preferential point for traffic concentration. On such basis, it was interesting to understand the deviations in the paths previously depicted assuming such bridge not traversable. According to site characterization analysis performed in terms of traffic in sub sub-chapter 3.3.2 "*Mactan mobility*", many different reasons may be hypothetically responsible to block urban mobility of Mactan Island. Plausible events which may hinder traffic on the bridge include traffic jams, vehicle accidents and maintenance works. The limitations mentioned can all be plausible conditions because, as it was described within the sub sub-chapter just mentioned and also confirmed by results of the accessibility analysis above described, the Sergio-Osmeña Bridge resulted being the busiest road connection because it offers only two lanes for streamline vehicles traffic, therefore it is the most prone to events which may hinder mobility.

Hereby, considering through ArcMap interface the insertion of a barrier located about the Sergio Osmeña Bridge, it was decided to perform once again the route-finding analysis and plot the best travel ways and related accessibility maps to check major deviations of solutions and indices with respect quantities previously depicted.




| FacilityID | Length_Rank | Path | Total_Leng_m | Minutes | AI_km_h |
|---|---|---|---|---|---|
| 1 | 9 | Location 1 - Location 1 | 5277,1 | 52,1 | 6,08 |
| 2 | 16 | Location 1 - Location 2 | 6311,9 | 18,7 | 20,2 |
| 3 | 10 | Location 1 - Location 3 | 5364,3 | 33,4 | 9,63 |
| 4 | 34 | Location 1 - Location 4 | 8959,2 | 24,7 | 21,78 |
| 5 | 35 | Location 1 - Location 5 | 9259,3 | 30 | 18,49 |
| 6 | 4 | Location 1 - Location 6 | 2559,7 | 24 | 6,41 |
| 7 | 999 | Location 1 - Location 7 | 7590,4 | 35,9 | 12,68 |
| 8 | 17 | Location 1 - Location 8 | 6437,9 | 37,7 | 10,24 |
| 9 | 38 | Location 1 - Location 9 | 9704 | 41,6 | 13,99 |
| 10 | 22 | Location 1 - Location 10 | 7340,8 | 28,4 | 15,5 |
| 11 | 40 | Location 1 - Location 11 | 10728,8 | 50,8 | 12,67 |
| 12 | 11 | Location 1 - Location 12 | 5415,5 | 63,2 | 5,14 |
| 13 | 42 | Location 1 - Location 13 | 11241,7 | 70,5 | 9,56 |
| 14 | 29 | Location 1 - Location 14 | 7986,9 | 20,8 | 23,05 |
| 15 | 24 | Location 1 - Location 15 | 7429,3 | 17,3 | 25,76 |
| 16 | 39 | Location 1 - Location 16 | 10150,1 | 62,6 | 9,73 |
| 17 | 28 | Location 1 - Location 17 | 7897,8 | 18,9 | 25,12 |
| 18 | 5 | Location 1 - Location 18 | 3502,2 | 26,9 | 7,81 |
| 19 | 19 | Location 1 - Location 19 | 6608,9 | 18 | 22,07 |
| 20 | 7 | Location 1 - Location 20 | 4328,9 | 17,3 | 14,99 |
| 21 | 37 | Location 1 - Location 21 | 9373,6 | 55,9 | 10,06 |
| 22 | 27 | Location 1 - Location 22 | 7895,2 | 26,5 | 17,9 |
| 23 | 6 | Location 1 - Location 23 | 3842,1 | 50,5 | 4,57 |
| 24 | 26 | Location 1 - Location 24 | 7620 | 31,1 | 14,68 |
| 25 | 31 | Location 1 - Location 25 | 8768,7 | 78,1 | 6,74 |
| 26 | 21 | Location 1 - Location 26 | 6849,1 | 16,3 | 25,18 |
| 27 | 23 | Location 1 - Location 27 | 7388,9 | 18,7 | 23,74 |
| 28 | 25 | Location 1 - Location 28 | 7594,5 | 73,4 | 6,21 |
| 29 | 8 | Location 1 - Location 29 | 5079,6 | 38,2 | 7,99 |
| 30 | 18 | Location 1 - Location 30 | 6475,2 | 26,9 | 14,45 |
| 31 | 33 | Location 1 - Location 31 | 8890,4 | 42,9 | 12,43 |
| 32 | 13 | Location 1 - Location 32 | 5760,3 | 59,2 | 5,84 |
| 33 | 1 | Location 1 - Location 33 | 855,4 | 9,7 | 5,28 |
| 34 | 15 | Location 1 - Location 34 | 6056,8 | 14,1 | 25,72 |
| 35 | 3 | Location 1 - Location 35 | 2407,3 | 44,1 | 3,28 |
| 36 | 41 | Location 1 - Location 36 | 11121,1 | 79,5 | 8,4 |
| 37 | 2 | Location 1 - Location 37 | 2089,8 | 6,2 | 20,23 |
| 38 | 12 | Location 1 - Location 38 | 5640 | 40,5 | 8,36 |
| 39 | 36 | Location 1 - Location 39 | 9365,2 | 26 | 21,58 |
| 40 | 20 | Location 1 - Location 40 | 6751,5 | 26,7 | 15,18 |
| 41 | 43 | Location 1 - Location 41 | 11731,1 | 93,2 | 7,55 |
| 42 | 30 | Location 1 - Location 42 | 8294,5 | 31 | 16,05 |
| 43 | 32 | Location 1 - Location 43 | 8840,7 | 24,2 | 21,9 |
| 44 | 14 | Location 1 - Location 44 | 5805 | 22,4 | 15,58 |

***Figure 30****: Network Analyst: Shortest itineraries in constrained traffic conditions*

As it was expected, indeed it is shown in *Figure 30* and in *Map 10*, major deviations were obtained in the case of travel length minimization because many earlier identified solutions were used to cross the closed bridge. On the other hand, for what concern time, itineraries resulted being almost unaffected by the presence of the barrier on that bridge. Indeed, with and without traffic limitation, common itineraries minimizing travel time use to cross Mactan Channel by the Marcelo Fernan Bridge because it is characterized by higher speed limits resulting in quickest journeys.

Moving onwards, were performed similar reasonings about the accessibility index AI on the base of constrained travel conditions. In the case of shortest routes, is strange note that one got higher accessibility indices because drivers are obliged to travel on roads on the right of Mactan Island, which generally are characterized by higher speed limits. While, in the case of quickest courses are derived similar accessibility indices because basically itineraries were not highly influenced by the hindered traffic on the Sergio Osmeña Bridge. Significant outcomes from the accessibility analysis conducted assuming constrained traffic conditions are shown in *Figure 31*. It describes the accessibility map corresponding to the shortest itineraries depicted by "Network Analyst" tool with the Sergio-Osmeña Bridge closed to traffic.

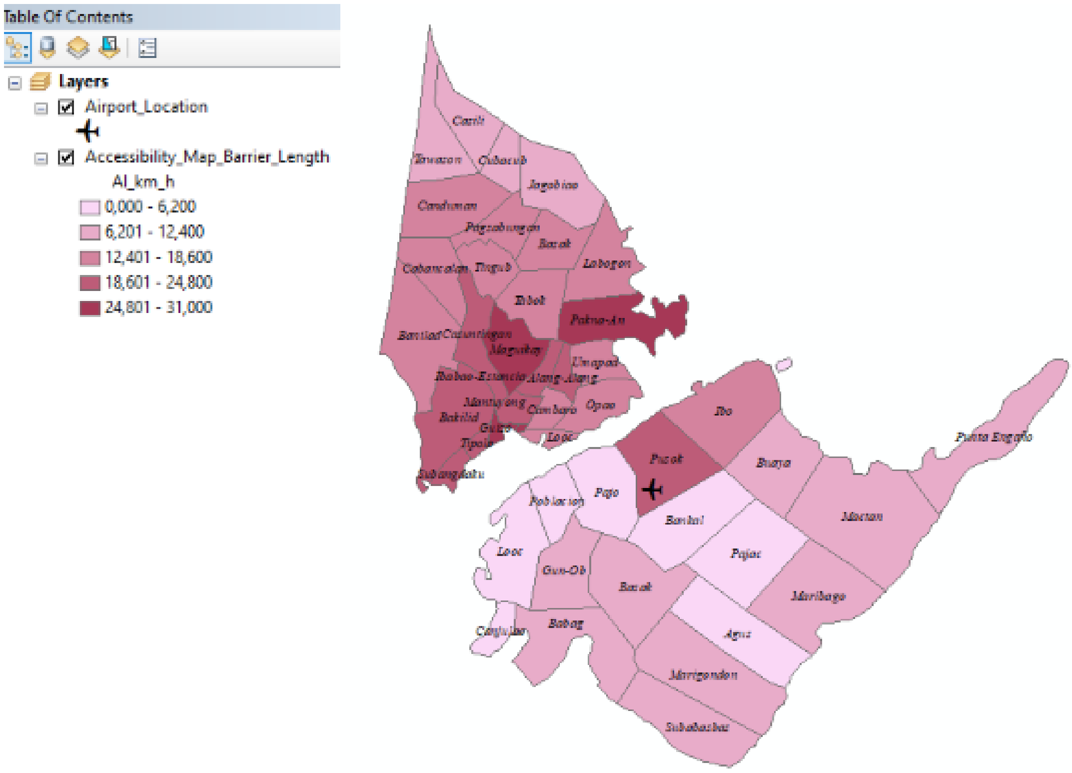



*Figure 31: Accessibility analysis: Map by Travel length in constrained traffic conditions*

For sake of completeness all remaining maps are reported in the Appendix at the end of the paper. As far as the constrained traffic conditions, maps within the Appendix include shortest itineraries and quickest itineraries, respectively in *Map 10* and *Map 11*, together with the corresponding comparison in *Map 12*. Follows the related accessibility maps respectively in *Map 13* and *Map 14*. Moreover, in the Appendix were collected extra comparative maps in different traffic conditions both for shortest itineraries and quickest itineraries, respectively reported in *Map 15* and *Map 16*.

### 3.5.4 City Mass Model

Simultaneously to best-routes analysis, to support the masterplan of mobility system on the territory under investigation, it was required to realize a 3D model of the area. A three-dimensional model better reflects the reality and allows to improve understanding, solve spatial problems and communicate design ideas easily. The mass model should include the surrounding of the International Airport of Mactan and bridges connecting Lapu-Lapu city with the main Cebù Island. As already mentioned, at last the mass model is supposed to be the base for the

design phase of the smart mobility Hub infrastructure included into the masterplan and then the starting point for the virtual reality driving scene creation, which actually is the thesis objective of engineer M. Fanshu and Z. Zheyuan.
To this aim, it was used ArcMap software to realize by means of polygons and planar geometries some 2D features describing different buildings insisting on the case study area. Precisely, for sake of model clarity and computational efficiency, edifices were divided by functional category and each class was assigned an average height. The following building categories with the corresponding average height were considered:

- Industrial Facility: 7,5 m
- Industrial Tank: 12,0 m
- Airport Terminal: 10,0 m
- Commercial Building: 4,5 m
- Shack: 3,0 m
- Modern House: 6,0 m
- Office Building: 20,0 m
- Hotel & Guesthouse: 10,0 m
- School & College: 10,0 m
- Hospital: 7,5 m
- Religious Building: 7,5 m

By opening ArcCatalog and by selecting "new shapefile" it was possible start creating new 2D feature class for each building category listed. Then, the editing started and at the end were modelled nearly 6300 2D features. Realized geometries were supposed to describe buildings mainly located in the area surrounding the Airport of Mactan and nearby bridges connecting islands. Once the editing phase was finished, each building database was assigned the selected average height as attribute data according to a float number format. In *Figure 32* is shown the result of the 2D editing phase carried out on ArcMap. Moreover, it was uploaded and integrated the road network realized and described in sub sub-chapter 3.5.2 "*Route-finding analysis*".

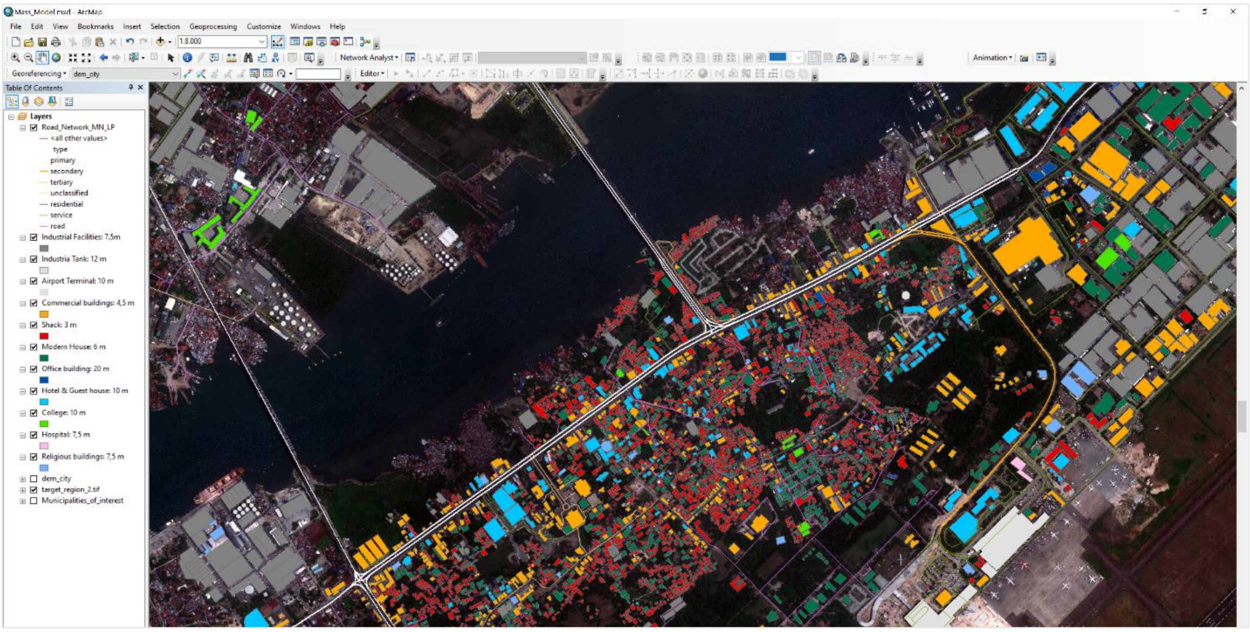



***Figure 32***: *ArcMap model: 2D editing phase.*

To finally obtain a 3D representation of the actual layout of the city, it was required to export the file into Arc Scene software for the realization of 3D building features. Indeed, these 2D features need to be extruded by another Esri programme that is Arc Scene. This application is commonly used to realize, visualize and perform spatial analysis on 3D models of real environments, such as the site investigated. Once having imported the file in Arc Scene, by opening the Property window of each feature class it was possible to extrude features selecting the field containing the "*Height*" attribute and then to assign a base elevation for features. The base height was imposed as the *MERIT DEM*, accurately described in sub sub-chapter 3.4.2 "*Raster Data: Digital Elevation Model (DEM)*". However, since the DEM geographically speaking describes a quite flat region it is meaningless, so the base elevation for the 3D model was neglected to preserve computational efficiency. In *Figure 33* and *Figure 34* it is shown the mass model obtained in Arc Scene by different sight perspectives.

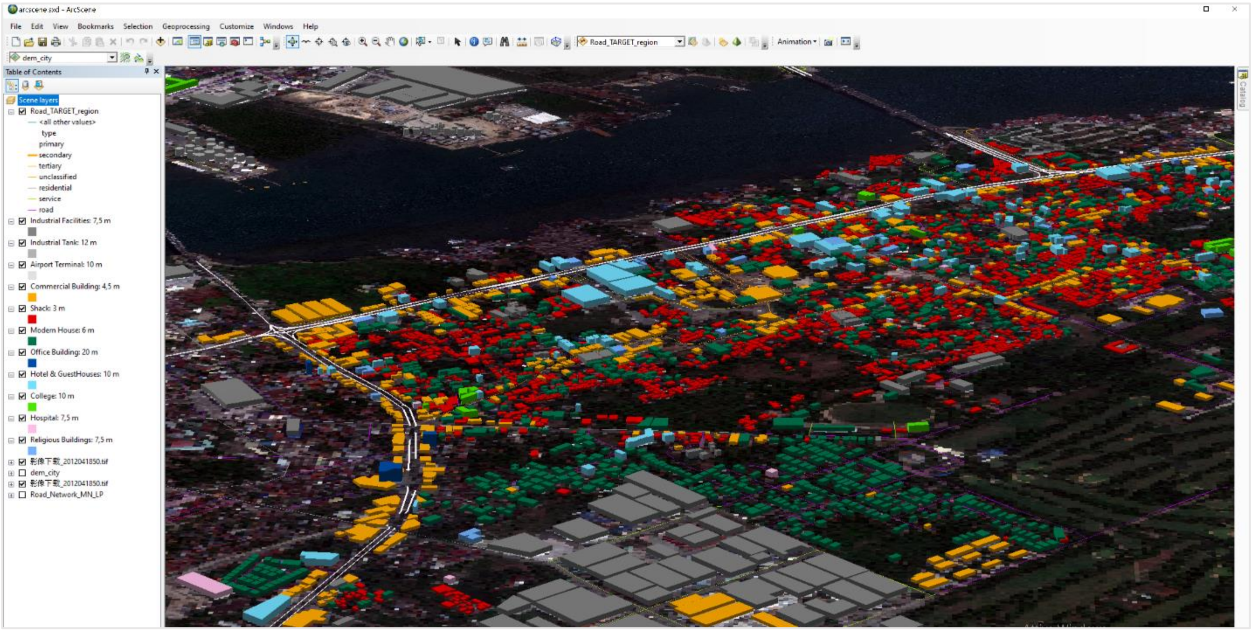



***Figure 33****: Arc Scene 3D mass model: general overview on Mactan channel and bridges*

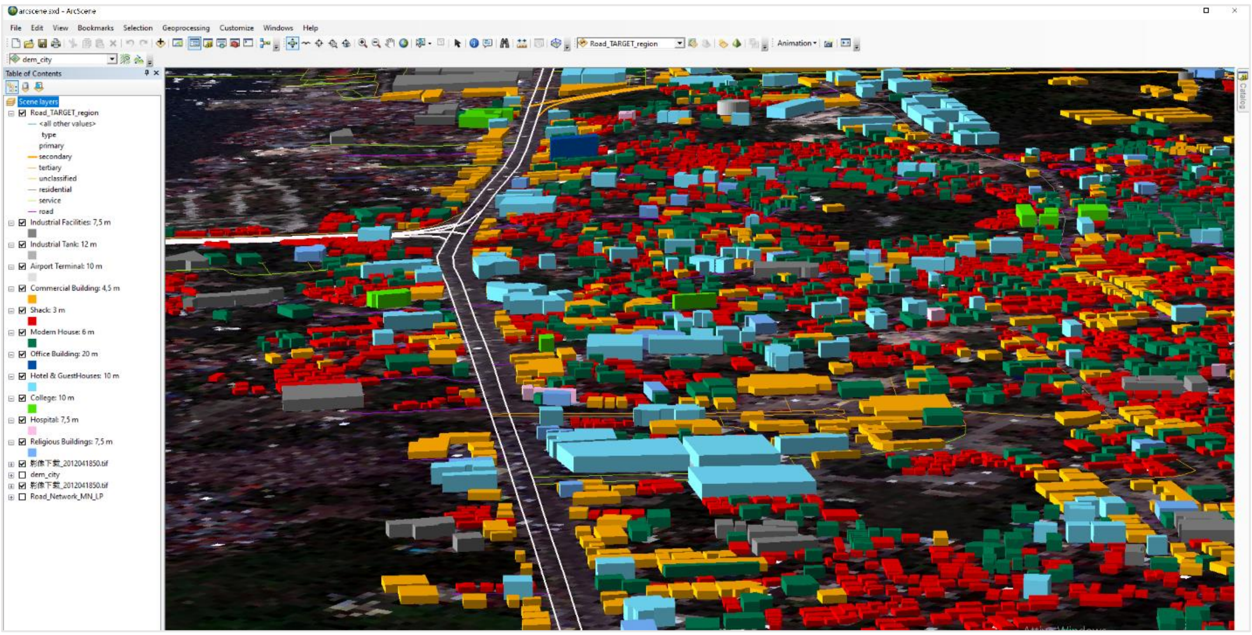



***Figure 34****: Arc Scene 3D mass model: M. L. Quezon National Highway*

Looking at the 3D mass model, the high concentration of red colour highlights the greater share of old and dilapidated shacks used as residences. However, there is a recently built residential area within the Benito-Mactan Aviation Airbase in the central part of the Island, recognizable by a well-organized set of green buildings in the mass model. The northern part of the Island is for the majority occupied by industrial facilities, described by grey prisms, while in the South-East, beyond the Airport, there is largest concentration of resorts and touristic activities.

## 3.6 S.W.O.T. Analysis

The S.W.O.T. analysis is a strategic-planning tool used to make strategic decisions with a long-term impact from the matrix of endogenous and exogenous factors, positive or negative, of an investigated system. Precisely, endogenous factors include strength and weakness points while threat and opportunity aspects are included within exogenous factors. This evaluation was left to the end of the research because its validity is directly linked to the completeness of knowledge acquired, at the time of its implementation, from results obtained by the analysis carried out in previous points of Chapter 3 "*Methodology*". Indeed, the subject focus of a S.W.O.T. evaluation, thus urban mobility system, must be studied in depth as well as the whole city context must be clearly defined to obtain satisfactory results.
On such basis after having performed an exhaustive case study characterization, addressed the problem definition, presented the data collection process and finally completed the GIS data analysis phase together with the interpretation of accessibility maps, following methodological step is the S.W.O.T. analysis. By investigating the mobility system of concern for the case study, was realized the S.W.O.T. matrix to scientifically support the decision-making process and firmly promote the selected development plan. To this aim, the analysis was carried out highlighting Strengths, Weaknesses, Opportunities and Threats of Mactan transportation infrastructure system.

### 3.6.1 Endogenous factors: Strengths and Weaknesses

Endogenous factors include all those variables internal to the system on which it is possible to intervene directly. Indeed, the analysis should be able to clarify Strength and Weakness points internal at the assessed system which have, respectively, a positive and negative effect on the mobility infrastructure itself.

*Strength and Weakness aspects*
As far as the system under investigation by the analysis conducted and presented in previous sub-chapters it was highlighted just one strength point. The only one mobility-connected strength factor which matters, for the case study, is the International Airport. The Mactan Airport is a technologically advanced infrastructure which was considered a key feature of urban mobility. Indeed, as outlined within sub-chapter 3.3.2 "*Mactan Mobility*" its presence directly, because of tourism, and indirectly, due to its important role in local economy, affects the Island transportation infrastructure.
For what concern weakness aspects, the matrix includes many issues treated in sub-chapter 3.3.2 "*Mactan Mobility*". Among the others there are the problems of a poorly designed and maintained road network, together with the oversaturation condition of bridges, the crowding condition of urban areas and finally the lack of suitable alternative solutions to urban mobility

than wheel transport by taxy, motorbike or old jeepney, which are, moreover, a threat because of polluting that they cause. The poor economy of the Country can be considered as one of main causes hindering the development and improvement of mentioned system drawbacks.

### 3.6.2 Exogenous factors: Opportunities and Threats

Exogenous factors are those variables external to the system which can however affect it. It is not possible to intervene directly on them, but it is necessary to keep them under control to exploit positive events and prevent negative occurrences which may develop. These factors derive from the market, the society or the external environment and are taken into account in terms of the potential risk derived by the product between the potential impact and the probability of occurrence. For the definition of opportunities and threats, it was performed a Risk evaluation on the outcomes of the P.E.S.T.L.E. analysis, which was supposed to identify market macro trends.

*P.E.S.T.L.E. Analysis and Risk Matrix*
The market macro trends analysis, basically an extension of the P.E.S.T. methodology, is a managerial framework based on investigating and monitoring the environment context in terms of macro trends capable to outline the existing scenario in which the system is included. The aim of such evaluation is finally to clarify which factors may be relevant in the decision-making process and what strategic choices to pursue. In detail, this framework allows professionals to address Political, Environmental, Social, Technological, Economical and Legal factors, influencing the system from the outside.
On such basis it was implemented this method to the case study of interest. Macro trends considered include, from the Political side the 2015 ongoing region development plan called "MetroCebù2050", the Philippine form of government and political actions aimed at promoting sustainable mobility, in terms of electric vehicles, and enhancing the usage of renewable sources of energy which, considering solar, hydro, geothermal and wind together, count for a small share of the total generating capacity, overall just the 29,3% [63]. Then, as far as Environment were considered the periodical natural hazards affecting the territory, such as flooding and typhon events, the truly high level of traffic pollution, above all due to emissions by old jeepneys used as public means of transport, as it was described within sub-chapter 3.3.2 "*Mactan Mobility*", and finally according to the limited extent in area of Mactan Island urban environment it was addressed and studied the feasibility of a micro-mobility solution by urban moving walkways. Follows, from Social trend point of view the population growth and urbanization phenomenon, which as it was reported in sub sub-chapter 3.2.3 "*Population distribution*" Philippines is experiencing as well as all the other developing Countries in the World and, at last, it was addressed as a threat the presence of thousands of foreign tourists because they worsen the urban crowding conditions during summer season. Moreover, considering Technological trends were taken into account innovations coming from the $4^{TH}$ industrial revolution such as IoT and Bigdata analytics introduced in sub-chapter 2.1 "*Digital Twin paradigm*". Finally, it was considered the poverty rate of the Nation, the GRDP index trend and researchions for job opportunities increments by 2050 described in sub sub-chapter 3.2.4. "*Economy*". Though, it must be highlighted the missing of relevant aspects to be mentioned for Legal trends included in the original P.E.S.T.L.E. framework of investigation. For sake of completeness are listed all trends just outlined above within the corresponding category:

- Political: Region development plan "*MetroCebù2050*", Airport tourists flow, Country form of government, sustainable mobility and electric initiatives, renewable sources of energy.
- Environment: Traffic pollution and jeepneys responsibilities, micro-mobility solutions for a tiny urban area, renewable energy source, periodical flooding and typhons events.
- Social: Population growth and Urbanization, poor housing conditions, crowding condition aggravated by the huge presence of foreign tourists during summer period.
- Technological: solution from $4^{TH}$ industrial revolution, thus Iot, BigData analytics and machine learning, to improve people life quality, in line with Society 5.0 principles, as well as smart transportation ideas in terms of mobility integration and sharing.
- Economical: GRDP index trend, potential growth of commercial activities, population poverty rate, job opportunity trend by 2050.

After having found those external trends having an impact on the system, it was performed the Risk assessment. The risk of a specific factor is evaluated by means of matrix showing the product between the likelihood of occurrence and the impact severity associated to the occurring of the specific event considered. This product returns the risk factor which then for the case study of interest was classified as follow:

- 0-1: Risk Null
- 2-3: Low
- 4-8: Medium
- 9-12: High
- > 12: Critical

| RISK | IMPACT SEVERITY | | | | | | |
|---|---|---|---|---|---|---|---|
| LIKELIHOOD OF OCCURRENCE | | Negligible<br>1 | Slight<br>2 | Moderate<br>3 | | High<br>4 | |
| | Rare<br>1 | NULL | LOW | LOW | | MEDIUM | |
| | Unlikely<br>2 | LOW | MEDIUM | MEDIUM | | MEDIUM | |
| | Possible<br>3 | LOW | MEDIUM | HIGH | • Electrical vehicles<br>• Summer crowding | HIGH | • Micro Mobility<br>• Iot and BigData<br>• Polluting vehicles<br>• Renewable energy |
| | Likely<br>4 | MEDIUM | MEDIUM | HIGH | • Population growth<br>• Urbanization<br>• Poverty rate<br>• Natural hazards | CRITICAL | • Smart Mobility<br>• Job opportunities<br>• High Tourist flow<br>• Cebù2050 Plan<br>• Traffic pollution |

***Table 5**: Risk analysis for opportunities and threats identification*

Having computed the risk factor for each external trend of concern, depending on *Table 5* were included within the final S.W.O.T. matrix just those Opportunities and Threats which resulted between high and critical risk.

*Opportunities and Threats*
Opportunities are those external factors if properly exploited can turn into strengths. Aspects having a high or critical risk factor, so considered relevant for the system under investigation, include the innovative solutions provided by technologies such as IoT and bigdata analytics coming from the $4^{TH}$ industrial revolution, the existing "*MetroCebù2050*" research for the sustainable development plan of the entire region, the implementation of electric vehicles integrated with micro-mobility solutions, considered suitable given the limited extent of the urban area of concern and the greater usage of renewable sources of energy, despite of coal, nowadays underexploited throughout the whole State. Moreover, a huge opportunity is offered by the high tourist flow disembarking in the Island at the International Airport of Mactan especially during summer months and the related job and financial opportunities this continuos flow of people makes it possible.
For what concern threats, are those risks at which the system is exposed to because of external environmental factors on which, as it is also for opportunities, it is not possible to exercise direct control. However, it must be thought some provisions in order to be capable of defending the system against potential negative impacts which may derive from a specific threat event occurrence. Threats having a high or critical risk factor, so considered relevant for the analysed system include climate conditions, which make the Nation prone to periodical harmful flooding and typhons events, the high population growth rate, the urbanization phenomenon, as well as city crowding during summer season. Moreover, were considered relevant those mobility habits of local people which are harmful for the environment, as it is for instance the use of polluting means of transport like jeepneys, and finally the poor economy of the zone together with the poverty rate affecting the majority of Cebuanos.

### 3.6.3 Decision-Making process

The set of endogenous and exogenous factors treated within sub sub-chapter 3.7.2 were included within the S.W.O.T. matrix summarized in *Table 6*. As it was mentioned at the beginning of sub-chapter 3.6 "*S.W.O.T. Analysis*" the identification of this matrix is essential for the achievement of final objectives. The list of factors composing the matrix serves as scientific support for the phase of strategy planning within the decision-making process of thesis research development. Indeed, a S.W.O.T. analysis cannot be considered completed if the listing and classification of internal and external factors, positive and negative, of the investigated system is not accompanied by initiatives aimed at catching opportunities by exploiting the strength aspects of the system and, at the same time, at finding solutions to save the system itself from probable threat occurrences. The phase consisting in the scientific identification of strategic actions to answer a problem is named decision-making process and can be considered as one of the last steps of study development.
According to the present sub sub-chapter the S.W.O.T. analysis must not stop at the classification of relevant factors but should takes advantage of the knowledge acquired and plan actions. These planned strategies on the base of all analysis carried out and information acquired during the research development should answer the presented problem about urban mobility in Mactan. Finally, as a result of the brain storming process, hypothesized strategies considered were the following:

- By leveraging bigdata analytics of thousands of daily passengers within the International Airport of Mactan, it would be possible to enhance the existing road network infrastructure, so accounting for real needs of users.
- Forecast alternative best itineraries, also in this case by exploiting technologies such as the Internet of Things and bigdata analytical methods, to decongest traffic in real time. It could be possible by mapping obstacle-free itineraries and by sharing path deviations through smart road signs or traffic totems for instance.
- Leverage the use of local and traditional means of transport like the Jeepney, widely used because of its comfortability, to promote sustainable mobility solution for the city such as the restyling of jeeps with electric engine.
- Realization of a Smart Mobility Hub to promote integrated solutions of sustainable urban mobility exploiting renewable energy from solar source.

Within *Table 6* is reported the final S.W.O.T. matrix and the whole of factors analysed to plan strategies. The set of factors described was created by developing the research and understanding time by time more deeply the issue of concern, starting from the case study definition, sub-chapter 3.1, up to the assessment of route-finding outcomes in sub-chapter 3.5. On the base of strategies bullet list, among hypothesized options to answer urban mobility problem of Mactan it was selected the integrated Hub. The intended mobility Hub would first address the lack of a strategic parking in the zone in between the two bridges, an area truly busy in terms of traffic. Second, the smart Hub would promote an integrated and sustainable solution to urban mobility of the Island, aiming to decongest traffic, reduce traffic pollution and $CO_2$ emissions taking advantage, among the others, of renewable energy generating capacity from solar source.

| STRENGTHS | WEAKNESSES |
| --- | --- |
| • International Airport of Cebù | • Poorly designed Road Network<br>• Neglected Pavements (unsafe driving conditions)<br>• Crowded Urban Environment<br>• Lack of smart mobility solutions and Infrastructures<br>• No railways<br>• Poor Economy |
| **OPPORTUNITIES** | **THREATS** |
| • IoT & Big Data Analytics<br>• «*MetroCebù2050*» Sustainable Development Plan<br>• Smart Micro-Mobility<br>• Electrical vehicles<br>• Renewable sources of energy<br>• High tourists flow<br>• Job opportunities from Tourism | • Natural hazards (flooding and typhones)<br>• Population growth<br>• Urbanization Phenomenon<br>• Summer Tourism Crowding<br>• Cebuanos mobility habits (polluting Jeepneys)<br>• Urban Pollution<br>• Poverty rate |

***Table 6****: S.W.O.T. Matrix*

## 3.7 Digital Twin Implementation

In summary an urban Digital Twin can be seen as a 3D replica of a city connected to the internet of things. This digital replica allows an efficient and evolved management of the city environment in near real time thanks to the visualization of infinite datasets collected via intelligent sensors distributed across the city. Echoing the starting sentence of sub sub-chapter 2.2.1 *"Examples of Urban Digital Twin implementation"*, Digital Twins have the potential to help deliver on many of the great challenges the world is facing today, including urbanisation, population growth, global warming, pollution, escalating infrastructure costs, and sustainable development planning.

Within the present research the objective is to address through a methodological Digital Twin the issue of urban mobility of Mactan carefully and deeply outlined as the investigation focus of present thesis paper. However, as far as the present thesis the Digital Twin implementation is a main future development of this preliminary and introductory work and it was treated in Chapter 4. Actually, the implementation is the final objective of a greater research to which the present thesis belongs to and which was realized in cooperation with automotive engineering students M. Fanshu and Z. Zheyuan. However, are given some insights about the Digital Twin implementation in order to justify contents treated in following sub-chapter.

Following this premise, the study aimed to an urban-scale mobility Digital Twin to get real time traffic data and perform micro and macro traffic simulation. Then, on the base of virtual experimentations the Twin model would allow to understand how at local scale the Mactan urban environment and road network would face the different travelling conditions derived by the implementation of hypothetical strategies and policies about mobility in order to be aware of their likely impacts on the built environment and so predict the behaviour of the area in many different case scenarios. Moreover, through the virtual model it would be possible to find and map best route itineraries depicted by AI-based software considering data acquired by virtual traffic simulation and both historical and near-real time traffic conditions recorded. In such a way, the Digital Twin would finally permit to reduce traffic congestion in real time by actively involving citizens and, as a consequence of that, to participate in reducing traffic pollution as it was supposed to. However, the idea proposed by the present research does not stop at the reproduction of the actual city environment, at real traffic simulation and at itineraries forecasting, yet it goes beyond that. Precisely, it aimed to the best masterplan of Mactan environment to address urban mobility issues in the Airport surrounding area considering added infrastructures and services than those already existing. From the S.W.O.T. Matrix derives the guessed strategy to answer this aim, that is the realization of a smart mobility Hub.

### 3.7.1 Mobility Hub solutions

Considering both reasonings outlined within sub-chapter 3.3 "*Problem definition*" and outcomes derived by analysis carried out in sub sub-chapter 3.5.3 "*Accessibility analysis*", actual mobility infrastructures resulted being inappropriate to support growing traffic of the urban district under investigation. Hereby, the Digital Twin involves the re-design of a limited portion of territory to facilitate the mobility in the entire region. As a result of that, it is supposed the realization of a smart and sustainable mobility Hub aiming to decongest traffic, reduce traffic pollution and improve Cebuanos quality of life through a better urban mobility. To this aim are hypothesized a mix of integrated and sustainable solutions to mobility. The just hinted mobility is described within next paragraph highlighting the themes of integration and sustainability on which the Hub

is based on. As far as integration the Hub provides a mix of vehicles to move within the urban area of Mactan. Indeed, people may use cars, motorbikes, scooters, bicycles, buses, a shuttle service and a pedestrian metro line which will be further analysed. As far as sustainability it must be though highlighted the electric nature of all mobility services offered at the Hub. Moreover, the installation of a photovoltaic system allows the sustainable production of energy from solar source. Hereby, to highlight that if were considered electric vehicles charged on grid by a mix of energy sources from coal to renewable, the advantage in terms of emissions would be just the half than vehicles full charged by renewable sources. Ideally, the idea is to realize a Hub which may reach plain sustainability by integrating macro and micro-mobility solutions and combining electric mobility with sustainable energy generating capacity from renewable sources.
Analysing innovative mobility solutions available at the Hub, it is guaranteed a commuting service Hub-Airport and is promoted an enhanced pedestrian mobility through a specific micro-mobility implementation. The commuting service consists of a fleet of electrical public shuttles, constantly on road, commuting the Hub with the International Airport hall. The micro-mobility implementation is an alternative and represent an even more sustainable and eco-friendly solution. It consists of two ways moving walkway for pedestrians which allows to reach the Airport, or back from it, effortless. The suggested auto-walk is a slow-moving conveyor mechanism which transport people across horizontal plane over short to medium distances. Nowadays this kind of solution is very popular within huge Airports to help people while travelling with heavy luggage from one terminal to another or as a connector to a parking facility or a ground transport. This technology is also used in urban areas such as in Hong Kong, one of the world's most heavily populated cities, where public escalators are used to connect downtown streets. The idea of using this technology as a public means of transport aims to effectively merge the above-mentioned functionalities. Thus, this innovative micro-metro should help both Airport passengers and local people of Mactan as an additional public service to urban mobility. It may be seen like an indoor metro for pedestrians which directly connects two important points of interest, the Hub and the International Airport terminal. Furthermore, to increase the attractiveness of this unusual service, to make it more feasible by an economic perspective and finally to encourage the community to use this micro mobility solution, an intermediate station is located in the middle of the metro development, near two important school buildings, the Philippine State College of Aeronautics and the Carmelite school. This eco-friendly mobility service would allow young people and teenagers to reach college and school every day in a sustainable manner reducing travel time. As it was just hinted, this intermediate stop allows to conceive the service like a “Metro for Pedestrians” which would be daily used by thousands of passengers, be they Cebuanos or foreign tourists, making the solution overall more suitable for Lapu-Lapu city environment and economy. As a result of that, this micro-mobility solution allows to answer many of the challenges the Hub was supposed to address, from urban traffic and pollution to the lack of sustainable mobility solutions. Finally, the urban area would benefit from a lower traffic level, a minor risk of traffic jams satisfying also the Hub requirement of lowering traffic pollutants emissions. However, the hub was not thought to address community needs of mobility only in terms of public and shared services with a sustainable approach, yet it is supposed to face, from the same environment-friendly perspective, the necessities of people travelling on own vehicles. Hereby, own vehicle driver needs are considered by installing many electric vehicles charging spots in the parking area. In this way it is possible also for common daily drivers to exploit the photovoltaic energy, produced by the system installed on parking roof, to recharge own electric vehicles including cars, motorbikes, bicycles and scooters in a fully sustainable manner.

## 3.8 BIM Data modelling

As it was reported at the beginning of sub-chapter 3.7 "*S.W.O.T. Analysis*" the definition of strengths weaknesses opportunities and threats about the investigated process is essential to clarify the last methodological step and finally get research goals. As a result of that, among options hypothesized within the above-mentioned sub-chapter to answer urban mobility problem of Mactan Island it was selected the last point of the bullet list. Accordingly, study efforts were focused on designing a smart mobility Hub in Mactan urban area to promote integrated solutions to sustainable urban mobility exploiting renewable sources of energy, in particular solar energy. Moreover, this idea would answer to the increasing need of a strategic mobility infrastructure within a truly trafficked area of the city.
To this aim, it was used the BIM-based software Revit for designing the mobility Hub model to be included within the VR scene which is the thesis objective of automotive engineering students M. Fanshu and Z. Zheyuan. The base of such model, which is now treated in terms of designed solution and implemented services, was the mass model realized in GIS and described within sub- sub-chapter 3.5.4 "*City Mass-Model*". This preliminary and low detailed mass model allowed to have some reference volumes and plan dimensions of the existing buildings which may interfere with the proposed mobility infrastructure and master plan of the surrounding region. In *Figure 35* is shown the overall model realized in Revit about the case study area. It can be recognized the parking area, divided in two, the photovoltaic system placed on roof infrastructure, which is supposed to provide enough energy to recharge all electric machines present, the entrance of the proposed sustainable micro-mobility solution for pedestrians, which lead passengers to some points of interest in the Hub surrounding and finally a green corridor leading to the existing Lapu-Lapu Sports complex which was also modelled.

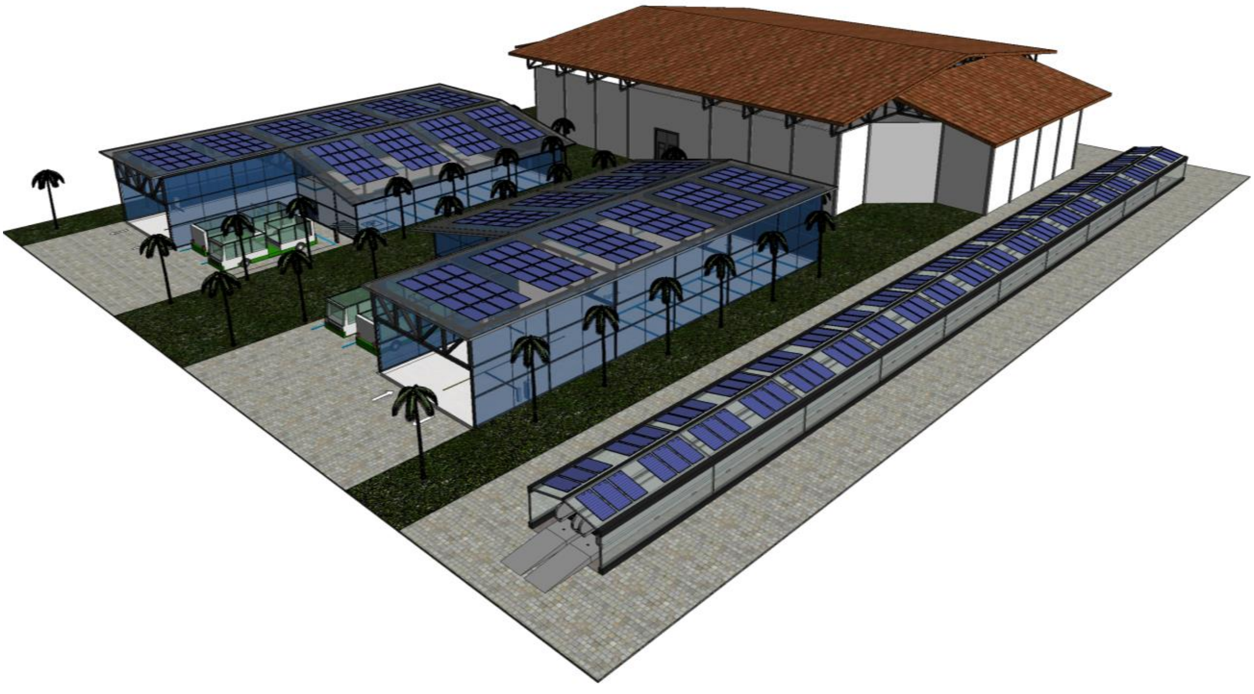


***Figure 35**: RVT Model: Smart Mobility Hub overview*

Clearly the parking area was divided in two smaller because it was required to maintain the access corridor to the Sports complex. This building is commonly used for events of different kinds from important basketball match to university graduation ceremonies and nowadays is a hotspot supporting the emergency due to covid-19 pandemic. To have an idea about the built environment surrounding the Hub it was modelled such Sports Complex. Given the few information and imageries from the website, the realized model was supposed to reproduce the inner structure which is made of steel trusses and concrete pillars with bricks infill walls. In *Figure 36* is shown the comparison between the modelled structure in Revit and the real structure from true photographs downloaded by internet.

***Figure 36****: RVT Model: Structure of Lapu-Lapu Sports Complex*

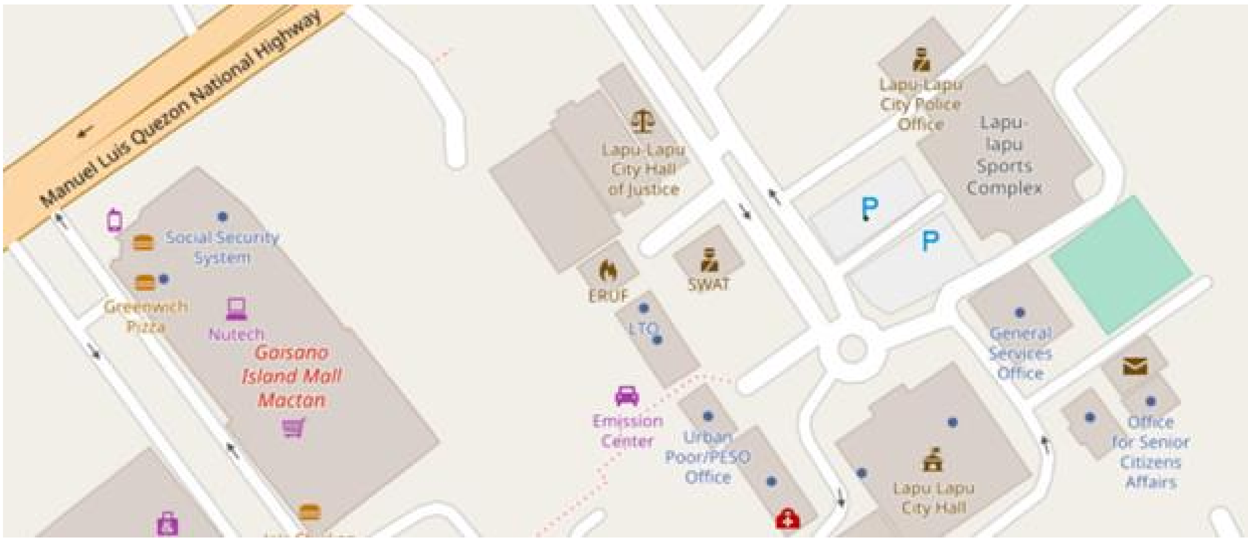
Source: Google Maps

### 3.8.1 Smart mobility Hub

Having introduced the Hub from a general perspective, now are highlighted and discussed some design choices taken. Precisely, about the Hub is analysed the geographic position, considered strategic for the placement of such infrastructure and the geometries of the planned area together with the typology and number of vehicles the Hub is designed to accommodate. As far as the innovative micro-mobility service, thought as a "Metro for Pedestrians", are described reasons beyond the selection of the best metro path in order to maximize the efficiency of the mobility service and address the majority of users considering stations nearby points of interest in the area. Then, it is addressed one specific walkways technology provided by the Thyssenkrupp company. Concerning the whole hub, is outlined the photovoltaic system installed on the hub infrastructures roof and its energy production capabilities.

*Geographical position*

The smart Hub was placed in a strategic location of about 2500 $m^2$ in between bridges of Mactan, precisely on an intersection of M. L. Quezon National Highway. This road is one of the principal connection link of the Island road network moreover resulted being, from the route-finding analysis performed within sub sub-chapter 3.5.2 "*Finding-Route analysis*", the most trafficked streets and so prone to jams. Another factor supporting the tactical placed selected, is the presence into the square of a rude parking which serve among the others the City Hall, the Tourism Office, the Hall of justice and the above-mentioned Sports Complex. *Figure 37*, actually a base map support of ArcMap software, shows precisely the Hub location in correspondence of the "P" signs and the surrounding buildings just cited. Moreover, considering the aim of producing photovoltaic energy to serve sustainable urban mobility within the city, the supposed area was considered adequate not only due to its proximity to important facilities, but because by an aspect analysis conducted on a GIS software it resulted being exposed to South. Such a terrain exposition is preferable because it allows to have a greater maximization of daily energy production. The aspect map considered for such evaluation is reported within the appendix as *Map 17* at the end of thesis paper.




Source: ESRI Base Map

***Figure 37**: Smart Mobility Hub location*

The Hub proposed includes also a micro-mobility service of pedestrian metro which allows users to have a fast walk from the Hub toward the International Airport of Mactan and even get some others intermediate points of interest for Cebuanos people. Considering the implementation of such service, the same location evaluation carried out for the Hub was even performed to select the best moving walkways travel path. The pattern was planned directly on the map considering a forest panoramic view during the journey and also in this case the best exposure of the infrastructure to maximize energy production of photovoltaic panels placed all along the 2 kms development of the pedestrian metro infrastructure. Since may be raised some concerns about feasibility in terms of costs and benefits regarding the implementation of such mobility walk infrastructure in the area of Mactan, it was decided to extend and develop the initial idea of urban moving walkways. On such basis, to justify the choice, demonstrate its social feasibility and additionally increase the appeal of this new sustainable service of micro-mobility, it was introduced the concept of a "Metro for Pedestrian". Basically, it is a superficial covered metro on which people may travel easily and fast by foot thanks a moving walkway which transport them quickly and in an eco-friendly way toward different points of interest within the urban area investigated without entering and worsening level of traffic of the already crowded downtown. On such basis as it was for the pattern even the three subway stations were located in strategic places. In detail, the first station in the Hub proximity, the second in the middle-metro development and the last at the Mactan Airport entrance. The aim of the station at the Airport is of course to help passengers while travelling with heavy luggage for considerable distances in the urban area. On the other hand, the station located at the Hub is thought to address both Airport passengers, going to the Tourism office for instance, and local people who wants to arrive in that square for errands at the City Hall or to assist any event at the Sports Complex centre. Finally, the station located in the middle point of the metro development is considered the most strategic on the territory because it may attract many additional users not related even to the Hub and to the city Airport. Users to address in this case are students, indeed this additional station was planned in between two important school buildings, the Philippine State College of Aeronautics included in Mactan Air Base and the EMD Carmelite School. *Figure 38* is supposed to describe the selected metro development in between the mobility Hub and the International Airport of Mactan. Moreover, are highlighted with red crosses metro stations at which pedestrians may embark or disembark the auto-walk and with yellow stars the points of interest in the surrounding area.


*Figure 38: Pedestrian Metro development*

Source: Google Maps

*Mobility Hub design*

The designed model was conceived with a steel structure, composed by trusses and columns, and glass panels, to realize facades and roof, in order to be at the same time modern and respectful of the surrounding environment. The area concerning the intervention is nearly 2500 m$^2$ while the two mirrored parking overall covers 1200 m$^2$ leaving free the entrance of Lapu-Lapu Sports Complex. The parking areas as designed may accommodate different kinds of vehicles, from cars, bus, motorbikes and scooter. Precisely were designed covered parking and recharging lots for 34 electric or hybrid cars and 8 motorbikes, while outdoor were placed 4 spots for electric bus and un-limited space for bicycle or electric scooter which may be left wherever in the square.

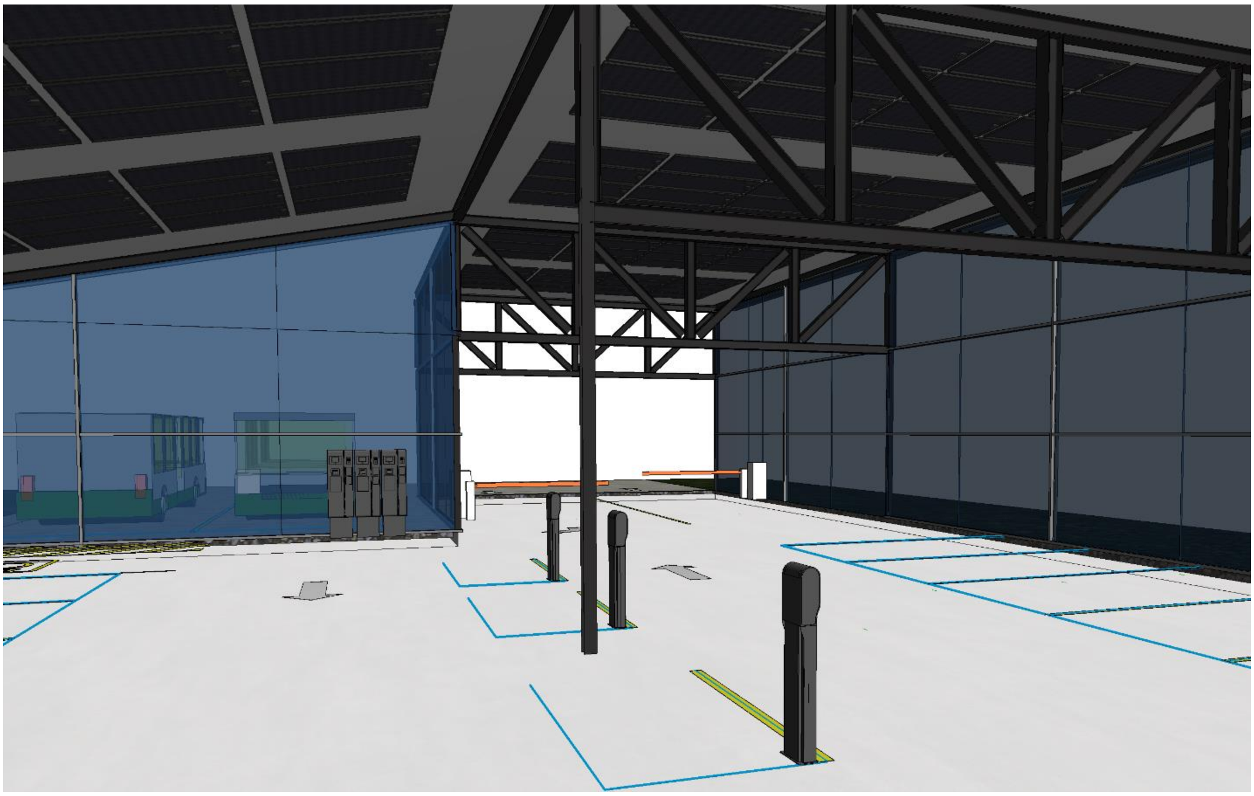


*Figure 39: RVT Model: Interior structure of parking areas*

In *Figure 39* is shown the inner structure of parking areas and the arrangements of recharging spots for different kinds of vehicles addressed.

As far as the metro service for pedestrians, it consists of a covered moving walkaway which, as it was discussed within the sub sub-chapter 3.7.1 "*Mobility Hub solutions*", allows to address many urban challenges the development plan was supposed to. This technology nowadays is very common in huge airports and increasingly popular in cities, it is an innovative micro mobility solution for small urban areas as is the Mactan case study. The metro develops for 2 kms crossing "*Mustang road*", "*Basa road*" and finally "*airport-departure road*". It is organized in three different stations, one at the Hub at the "*lapu-lapu city hall road*", one at the Airport of Mactan in "*airport-departure road*" and another in the between the two, in "*Basa road*". The system is constructed by ThyssenKrupp technology in modulus from 100 to 500 meters. As it is reported by the official website of Thyssenkrupp, the conveyor is designed to reach a maximum speed of 7,2 km/h, around 2 m/s, permitting to 7300 passenger per hour to cross the entire tunnel in nearly 15 minutes per direction [75]. Such technology allows a continuous walking with no waiting time and reaches its max efficiency on medium distances, about a km, as it is for the case study. The limited are of interest is one of the reasons why this solution was thought feasible for the case study of Mactan urban environment. In *Figure 40* is shown the designed moving walkaway.

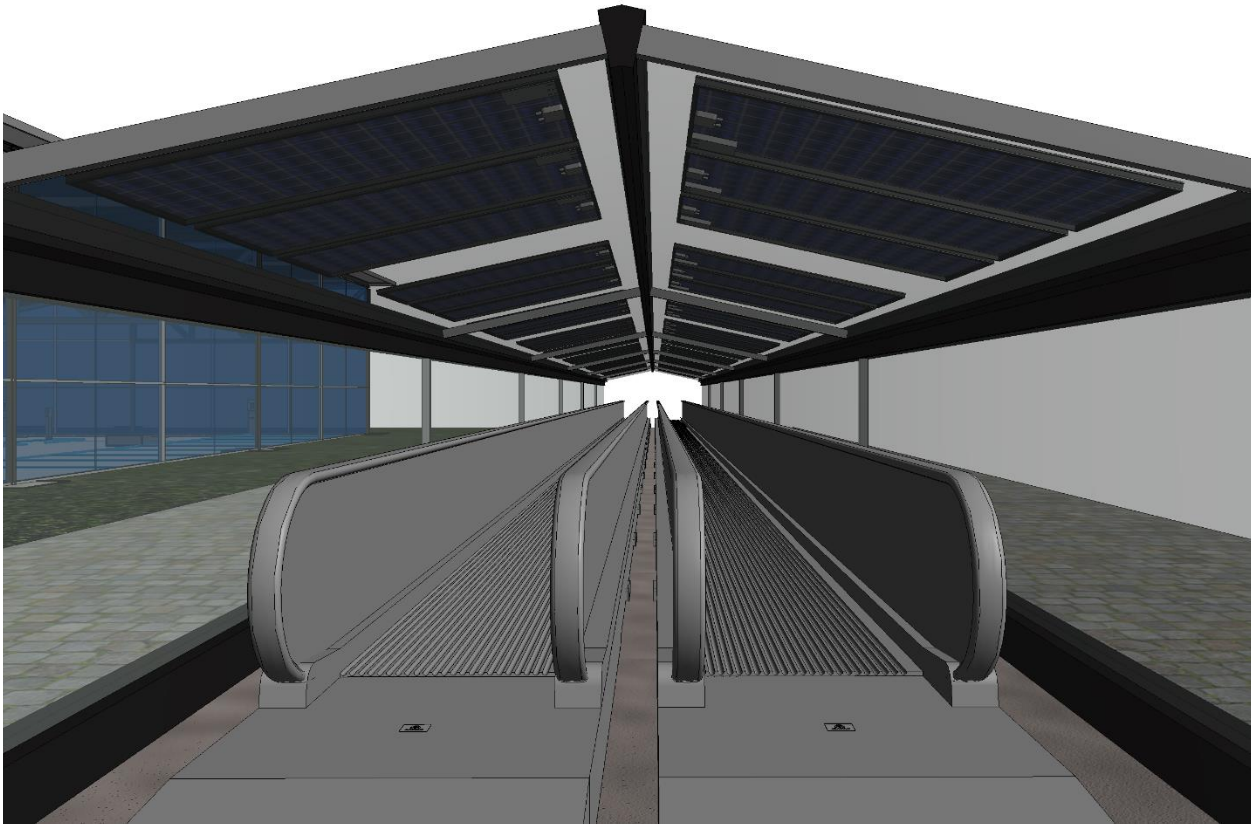


***Figure 40****: RVT Model: Moving walkways*

*Photovoltaic system*

Photovoltaic but more in general renewable energy is not exploited at its best in the Country even if the Government is promoting its implementation with several acts. As a result of that, since the intended mobility Hub aims to self-sustainability it was suggested the implementation of a photovoltaic system to generate energy from solar source with the aim of supporting the electric mobility promoted by the Hub in its different forms, from cars to the moving walkway. Moreover, as it will be clarified next, the suggested system would allow to produce enough energy to feed also cooling and lighting system of the Hub. The photovoltaic system is composed by 320 panels placed on roof of parking areas, in group of sixteen, and 2400 panels spread along the 2 kms of walkways, for a total number of 2700 installed panels. The panel typology is the same and is characterized by a power of 320 W. In *Figure 41* is reported a top view of the Hub area, by which is visible the photovoltaic panels arrangement.

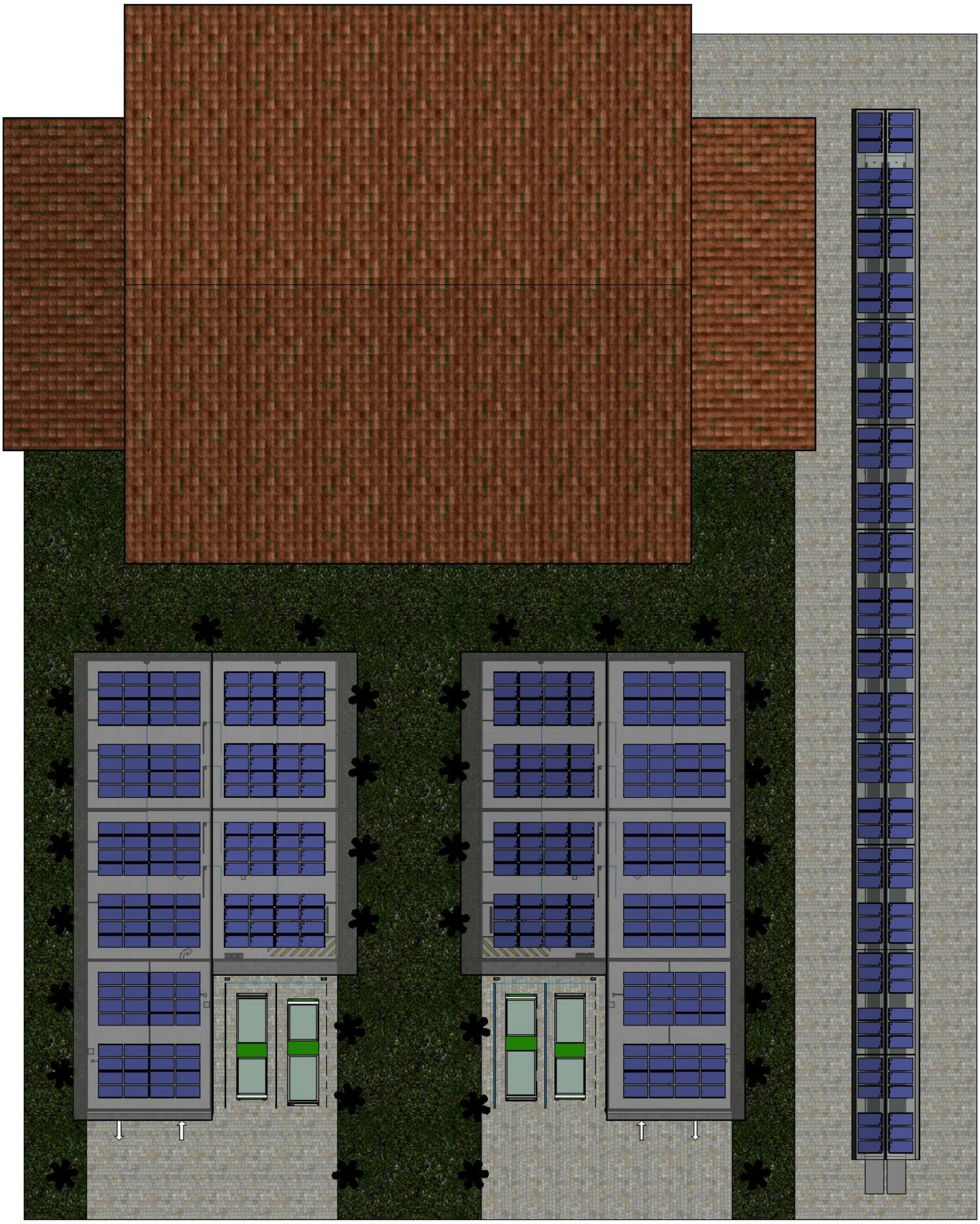


***Figure 41**: RVT Model: Photovoltaic system arrangement*

By analysing the photovoltaic configuration, it was found suitable for the purpose of making the Hub full-sustainable. Indeed, assuming to want a system capable to recharge the entire fleet of vehicles in the hub it is required the following capacity. As far as cars, the maximum parking capacity is 34 vehicles and averagely a battery of 40 kW each. For what concern electric buses, at maximum they could be 4 requiring 600 kW each. At last, indoor may be recharged simultaneously 8 motorbikes which are equipped with a 2kW battery. Summing up is possible to obtain the total battery requirement of about 3800 kW. For sake of simplicity for the computation of energy generation capacity of the photovoltaic system configuration described, were consider only central hours of the day because these hours guarantee the maximum productivity of a panel. Thus, assuming 4.5 hours of full sun and dividing one gets the power of the system, that is 850 kW h. Having selected panel of 320 watt each, by diving the system power for 320 one gets the total number of panels which are required to charge in 1 hour the entire fleet capacity of the Hub. The final number obtained by this computation is, rounding up, 2650 panels.

However, within this analysis was not considered the electric requirement of the walkways because it was not possible to acquire this information from the web, but anyway we know that is a 3+ A energy class. Despite this omission, as it was above hinted, the system can be considered satisfactory since the recharging time of a car is still longer than one hour, so it is assumed that part of the energy can also be used for the conveyor power supply as well as for lighting and cooling systems of the Hub. Otherwise, if the electrical potential would not result enough, it was hypothesized one more solution. Precisely, it could be possible to exploit the roof surface of the Sports Complex to place more panels and increase the power generating capacity of the system in order to truly satisfy the intended idea of providing a real support to the electric mobility and the sustainability promoted by the Hub.

# CHAPTER 4:

# FUTURE DEVELOPMENTS & CONCLUSIONS

Echoing final reasoning of sub sub-chapter 3.6.3 "*Decision-Making process*" about the sustainable development idea of Mactan environment in terms of urban mobility, it can be assumed a smart mobility Hub which address this great problem in the area by promoting sustainable and integrated solutions aiming to better mobility and lower traffic pollutions to get improvements as far as urban living.

The implementation of the intended Hub and its integration with technologies supporting a Digital Twin, such as IoT and big data analytics, is the main future development of the thesis project. Indeed, the smart Hub described so far, just resumed in Chapter 4 introduction, coupled with Digital Twin technology may address many of the potential fields of investigation of an urban case, from traffic monitoring to travel forecasting, as described in sub-chapter 3.2 "*Urban DT*". Moreover, the Hub coupled with a Digital Twin may involve other strategies, than the mobility Hub, among those derived by the S.W.O.T. analysis performed in sub-chapter 3.6. From a general perspective the Digital Twin is supposed to exploit technologies introduced by the 4$^{TH}$ industrial revolution to get improvements for people life quality according to base principles of Society 5.0. In detail, the urban Digital Twin desired aims by implementing these technologies to forecast and map alternative obstacle-free itineraries to decongest city traffic in near real-time by AI-based software which interpret both historical recorded traffic information and real-time acquired traffic data. Moreover, considering the installed photovoltaic system and the purpose of predict both real and potential amount of energy daily produced on the base of weather conditions and historical meteorological data, the aim is to further optimize intelligently driver's mobility experience. Indeed, Digital Twin's best predicted itineraries are intended to be calibrated in terms of recharging time and energy requirements considering Hub projections on the amount and types of vehicle which may be charged within the Hub itself. At the same time, the Digital Twin platform may record and display the level of pollutants and $CO_2$ in the air urban environment by monitoring traffic conditions. Then, as a further development, data concerning the emission share belonging to different types of vehicles together with the simulation environment of urban mobility can sustain decision makers on specific strategies of development to pursue and sustainable initiatives devoted to further improving air quality and other transport related aspect within the city. From a practical point of view, the Digital Twin for citizens can be materialized with an internet traffic-connected App. This App is intended to promote a sustainable and integrated mobility, as it was carefully described so far, by showing users best itineraries to reach the desired destination and travel tips as the more sustainable means of transport on which embark among those available at the Hub for a specific journey.

As far as other strategic actions derived by the decision-making process following the S.W.O.T. analysis, it may be addressed the public mobility. For instance, since Philippine's people are truly fond to traditional Jeepneys, because of the insight cultural heritage of these historical means of transport, not allowing scrap them, the government is promoting a series of activities to renovate old World War II Jeepneys in terms of engine, aesthetics and provided services. Once the ruined and polluting Jeepney versions will be completely renewed and running on Philippines's roads, the Hub could be the terminus station for new public electric jeepneys, which will enhance sustainable mobility habits of Philippines' people.

To summarize, the final Digital Twin desired is a virtual replica of the environment used to improve people life quality by means of optimized itineraries depicted by AI-based software

taking into account traffic conditions, sustainability of mobility solutions, weather information and energy requirements. Moreover, the technology may be exploited in advance by policymakers in order to test the validity and potential effects of any urban strategy on the area, for instance in terms of mobility or air quality.
A further and greatest Digital Twin development regards the extension of this technology to all other aspects of concern than mobility. For instance, among the others, are matter of concern people health and safety within cities, the risk against flooding and typhoons hazards which affect the whole Country and even the correct management of building assets and infrastructure construction, increasing in line with the Country growth.

## 4.1 CONCLUSIONS:

The present thesis has allowed me to discover, understand and learn from a methodological perspective the potential of developing a Digital Twin for the masterplan of a smart city, precisely a smart urban area. Whereby smart city means the combination of hardware components collecting data, dedicated software for the smart management of hardware and a communication network connecting all elements between each other.
As many times outlined within the paper, the present thesis is part of a greater research to which collaborate automotive engineering students M. Fanshu and Z. Zheyuan. The thesis main goal was to set-up a scientific based methodology for the definition of a Digital Twin at urban scale. Precisely the case study was focused on urban mobility recognized being one of the main problems of the area under investigation. The key to the research, which is also the basis of smart development projects and related masterplans, was to investigate mobility in its whole complexity not addressing only one specific aspect of matter. This approach has ensured the possibility to have a general framework of analysis fully convergent toward decisions taken during research development.
As conclusive comment about the present study, given the rapid development that cities are experiencing in terms of population, size and energy consumption, the mobility management Twin supplied aimed at improving the urban living of Mactan and people life quality by means of industry 4.0 technologies and by addressing some of the seventeen sustainable development goals adopted in 2015 by UN 2030 Agenda, and shown in *Figure 42*. Hopefully, the present neighbourhood mobility development may be the driving force to give rise similar sustainable developments throughout Philippines's cities.


***Figure 42***: *Sustainable Development Goals*

Source: United Nations. https://sdgs.un.org/goals

# RINGRAZIAMENTI

Due anni di lavoro intenso e un anno di ricerca approfondita per la stesura della presente Tesi di Laurea Magistrale mi hanno portato oggi con estrema gratitudine a celebrare insieme il titolo di Dottore in Ingegneria Civile e il mio ventiquattresimo compleanno. Vorrei però che il merito di questo successo raggiunto con determinazione sia condiviso con alcune persone.
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Parlando delle persone a cui tengo, un ringraziamento speciale va ai miei genitori.
Mamma e Papà vi ringrazio perché ho iniziato questo percorso dopo un periodo difficile per la mia salute e dopo poche settimane dall'inizio ho dovuto riaffrontare lo stesso ostacolo e le stesse paure di pochi mesi prima, ma con voi al mio fianco è stato tutto più facile. Vi ringrazio anche perché in questi ultimi mesi lo studio diventava sempre più difficile per via della stanchezza e della voglia di finire ma con voi ho sempre trovato un confronto che mi ha portato a crescere, prendere decisioni e seguirle con onore. Infine, grazie per questi lunghi 5 anni perché mantenendomi economicamente mi avete permesso di concentrarmi unicamente e completamente sull'università in modo da finire nel minor tempo possibile.
Ringrazio infinitamente la mia compagna Federica perché in questo ultimo anno con lei mi sono sempre sentito compreso, spronato e soprattutto ascoltato, anche quando mi rendevo io stesso conto di essere pesante ed esagerato nelle mie reazioni. Sono orgoglioso di festeggiare con te, perché mi hai dato tanto durante il percorso per raggiunge questo traguardo ed hai vissuto con me le mie paure e preoccupazioni.
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Grazie

Daniele Iunti
22 Luglio 2021, Torino

# ACKNOWLEDGMENTS

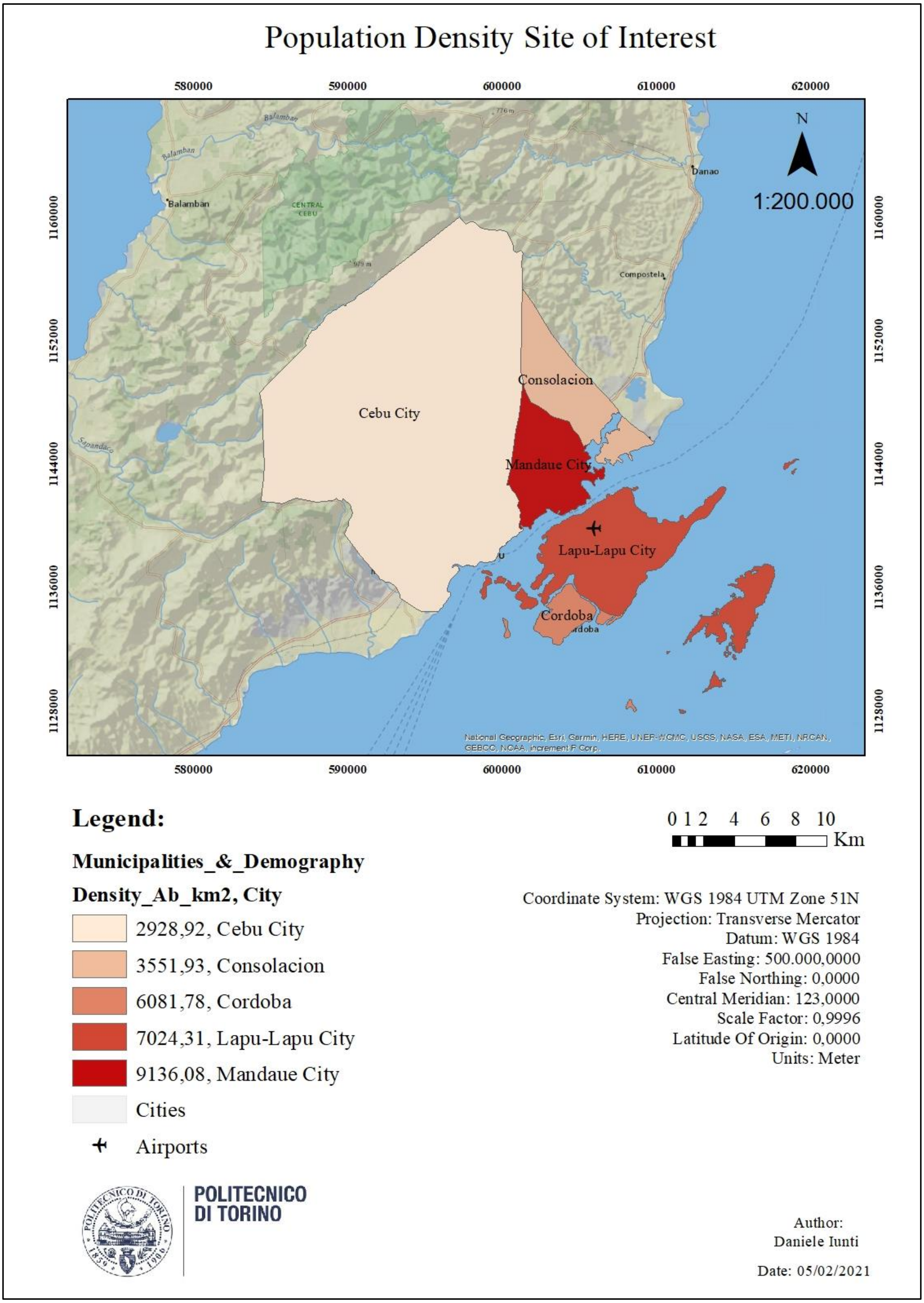
Two years of intense work and one year of in-depth research for the writing of the present Master of Science's thesis led me today with great gratitude to celebrate together the title of Doctor of Civil Engineering and my twenty-fourth birthday. However, I would like the merit of this success achieved with determination to be shared with some people.
First, I would like to thank Prof. Anna Osello and Prof. Francesca Ugliotti, respectively Supervisor and Co-relator of this paper, for the great support given to me in a prohibitive social situation. In choosing the innovative line of research and the Cebù case study, not well outlined initially, the enthusiasm and trust that you have passed on to me from the beginning were fundamental.
Talking about people I care about, a special thanks goes to my Parents. Mom and Dad thank you because I started this path after a difficult period for my health and after a few weeks from the beginning I had to face the same obstacle and the same fears of a few months before, but with you by my side everything was easier. I also thank you because in recent months studying has become increasingly difficult due to tiredness and the desire to finish, but with you I have always found a confrontation that has led me to grow, make decisions and follow them with honour. Finally, I thank you for these long 5 years because by supporting me economically you have allowed me to focus solely and completely on the university to finish in the shortest possible time.
I infinitely thank my fiancee Federica because in this last year with her I have always felt understood, encouraged and above all listened to, even when I myself realized that I was heavy and exaggerated in my reactions. I am proud to celebrate with you because you have given me so much along the way to reach this milestone and you have lived with me my fears and worries.
I also thank my best friend Fabrizio because since school talking with him has always been stimulating and helpful for me to better detail my dreams and work to achieve them.
Finally, a special thanks to my friend Vanessa to whom I never told of the importance of her support for me. Without you I would never have started this path in English, and I would never have lived some university experiences that I will always carry with me.

If in five years I have reached these important milestones, this is also due to your support. Thank you.

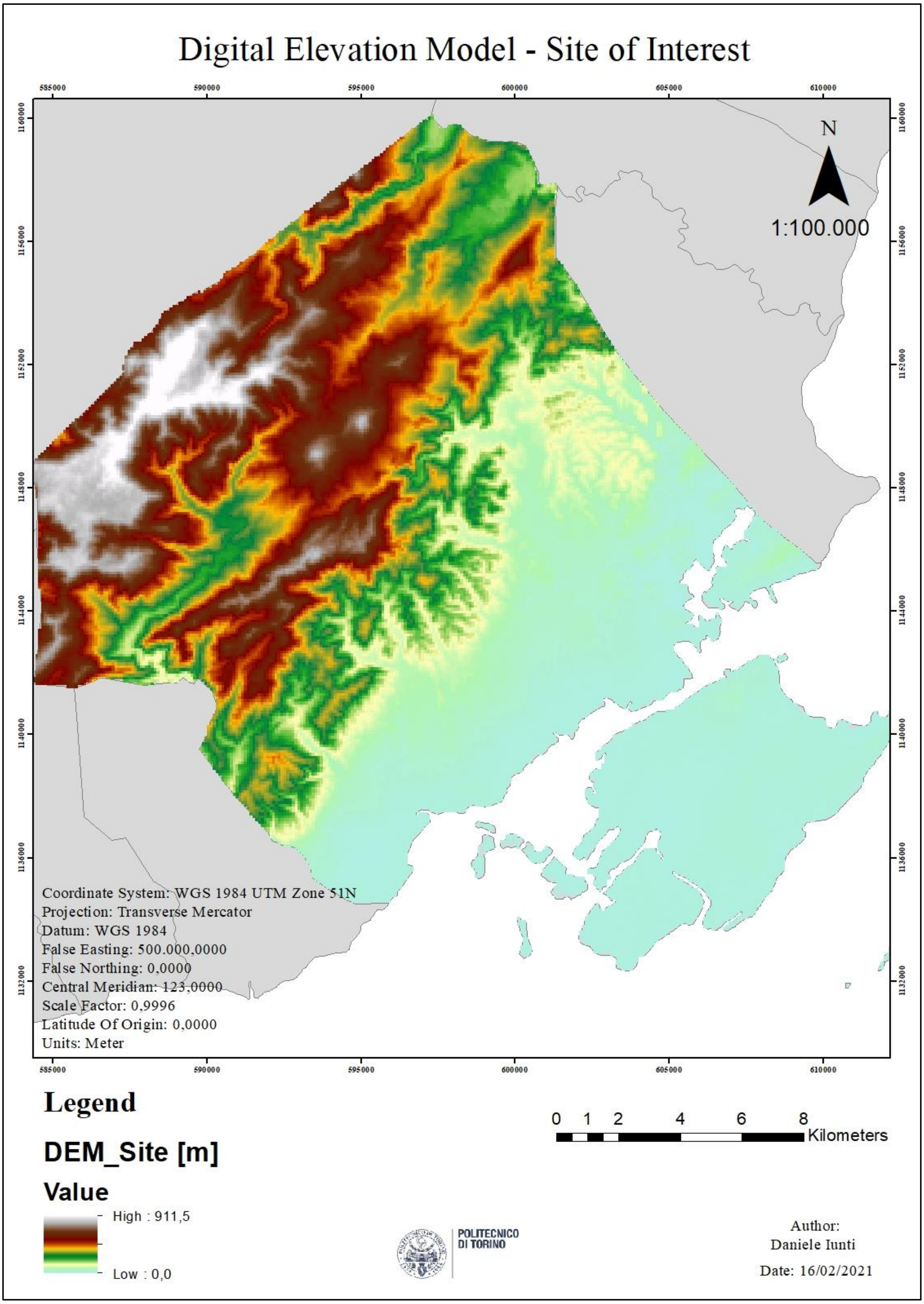
Daniele Iunti

22ND July 2021, Turin

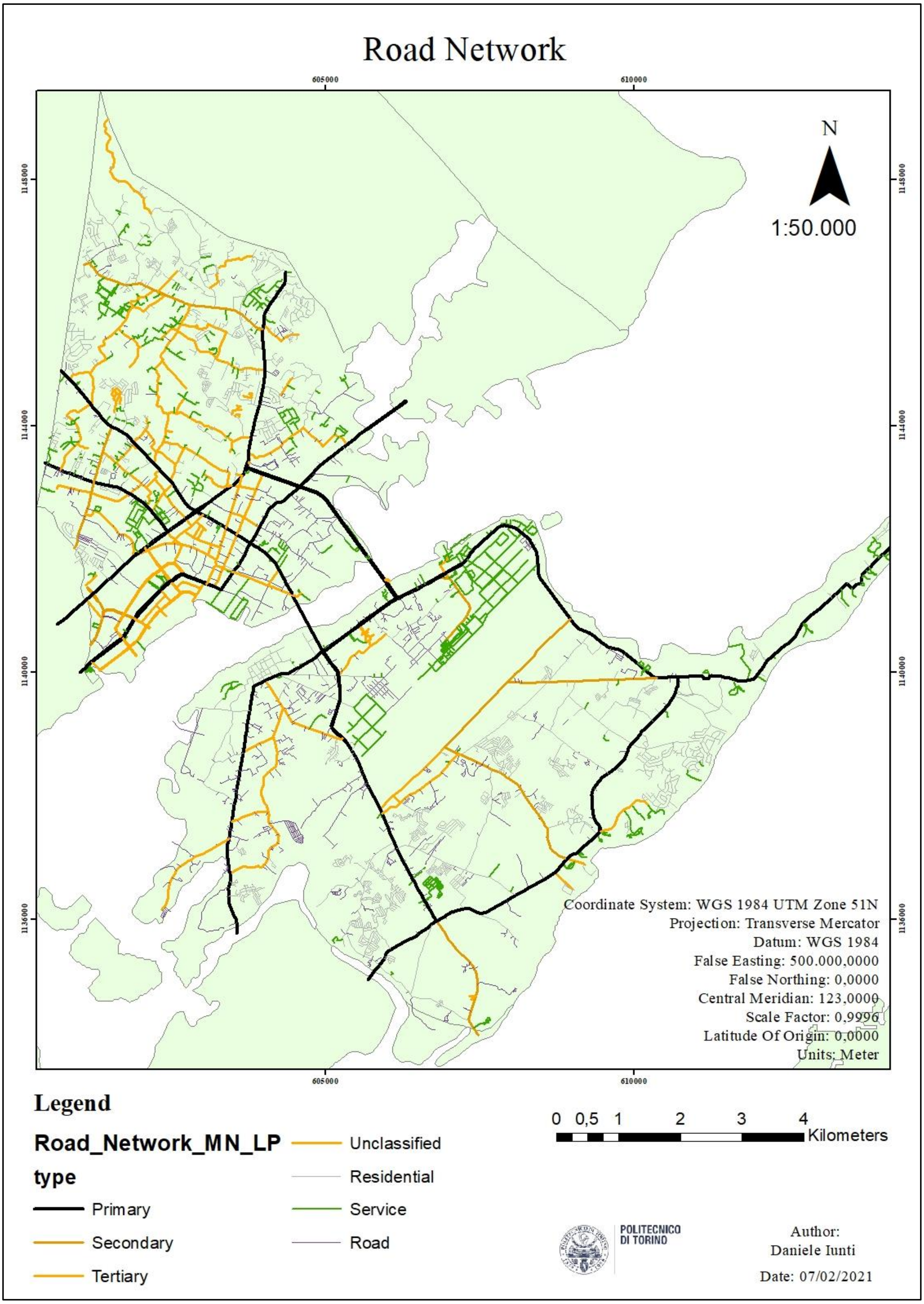
# APPENDIX



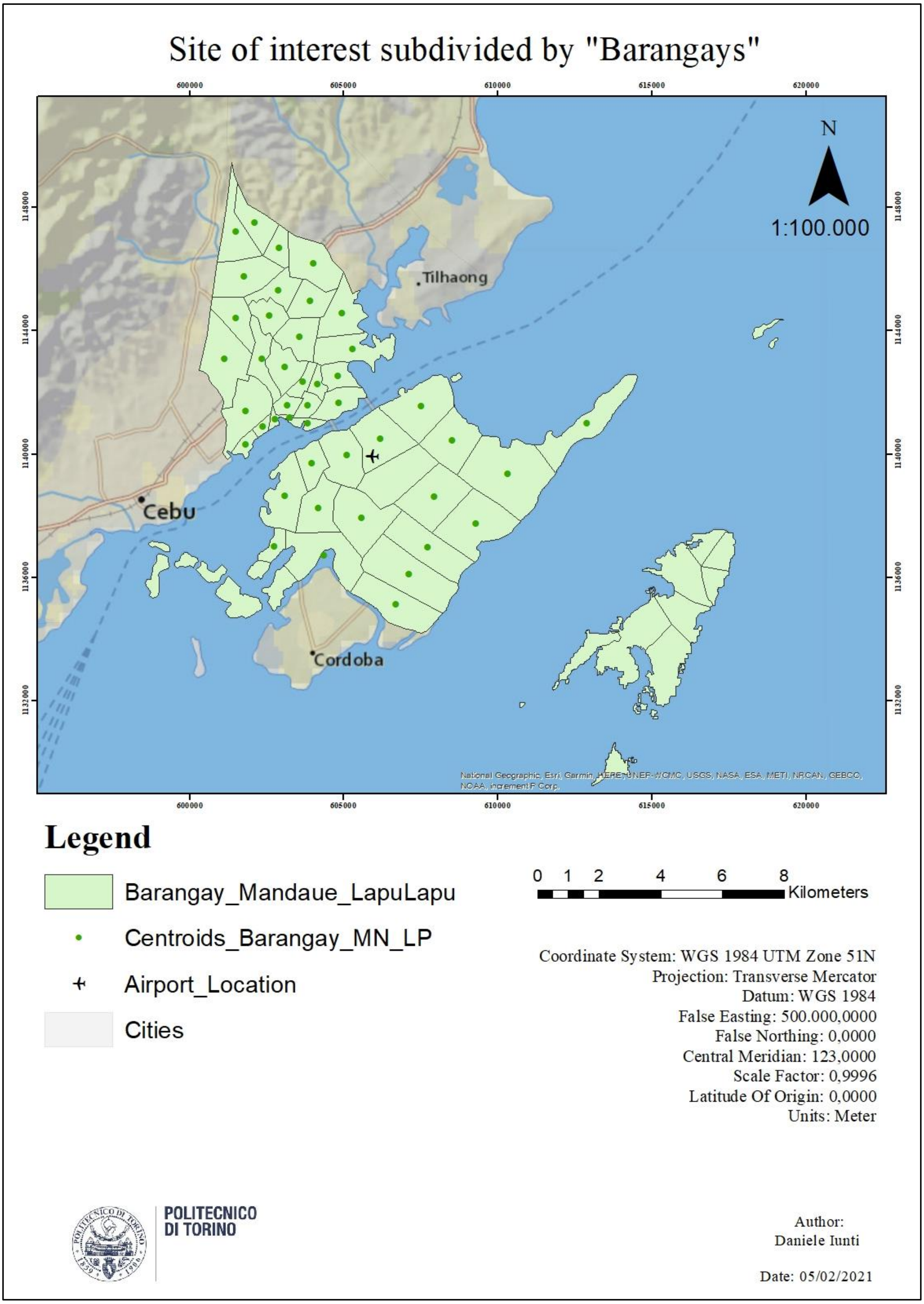

***Map 1**: Population density*



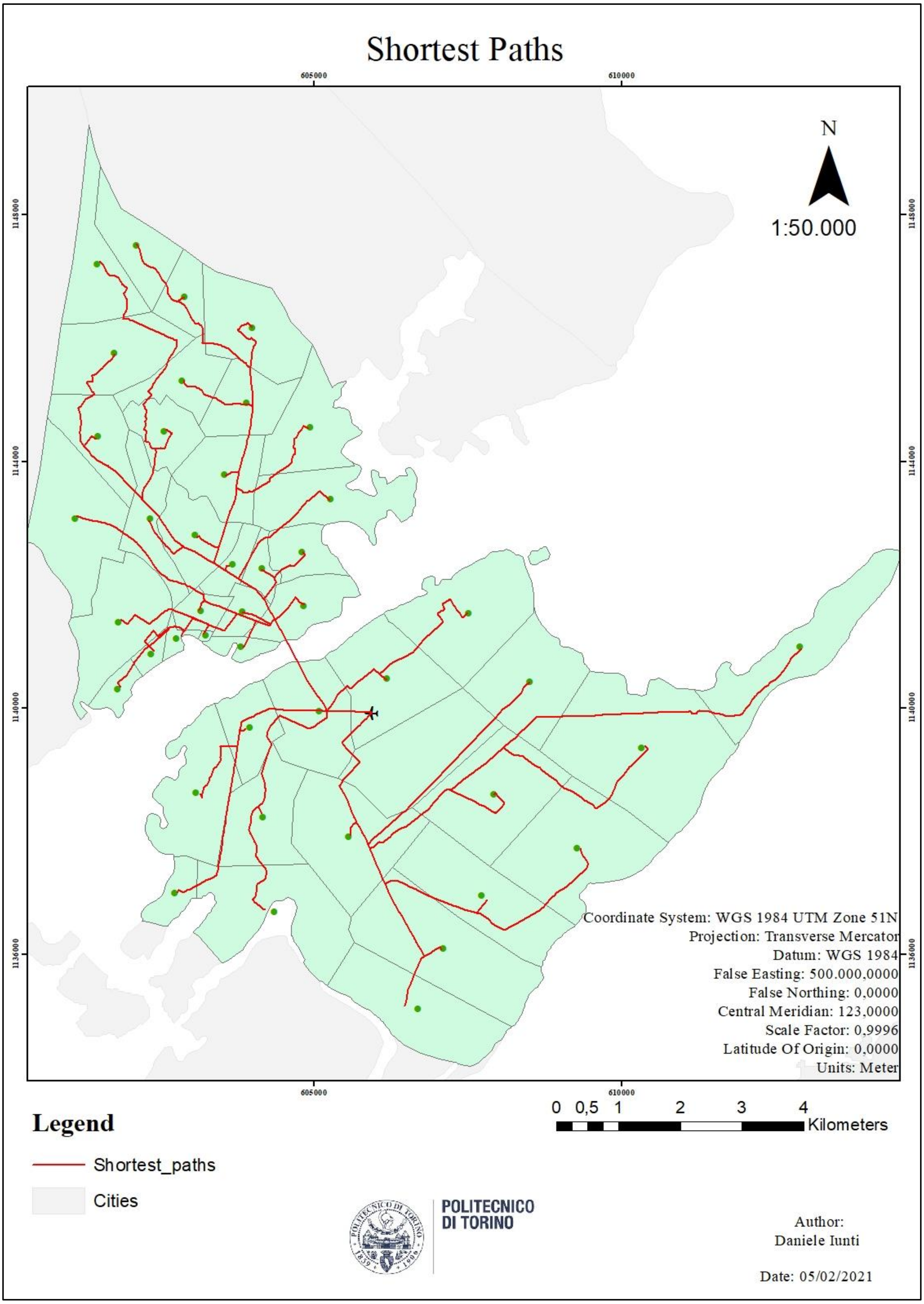

***Map 2**: Digital Elevation Model*



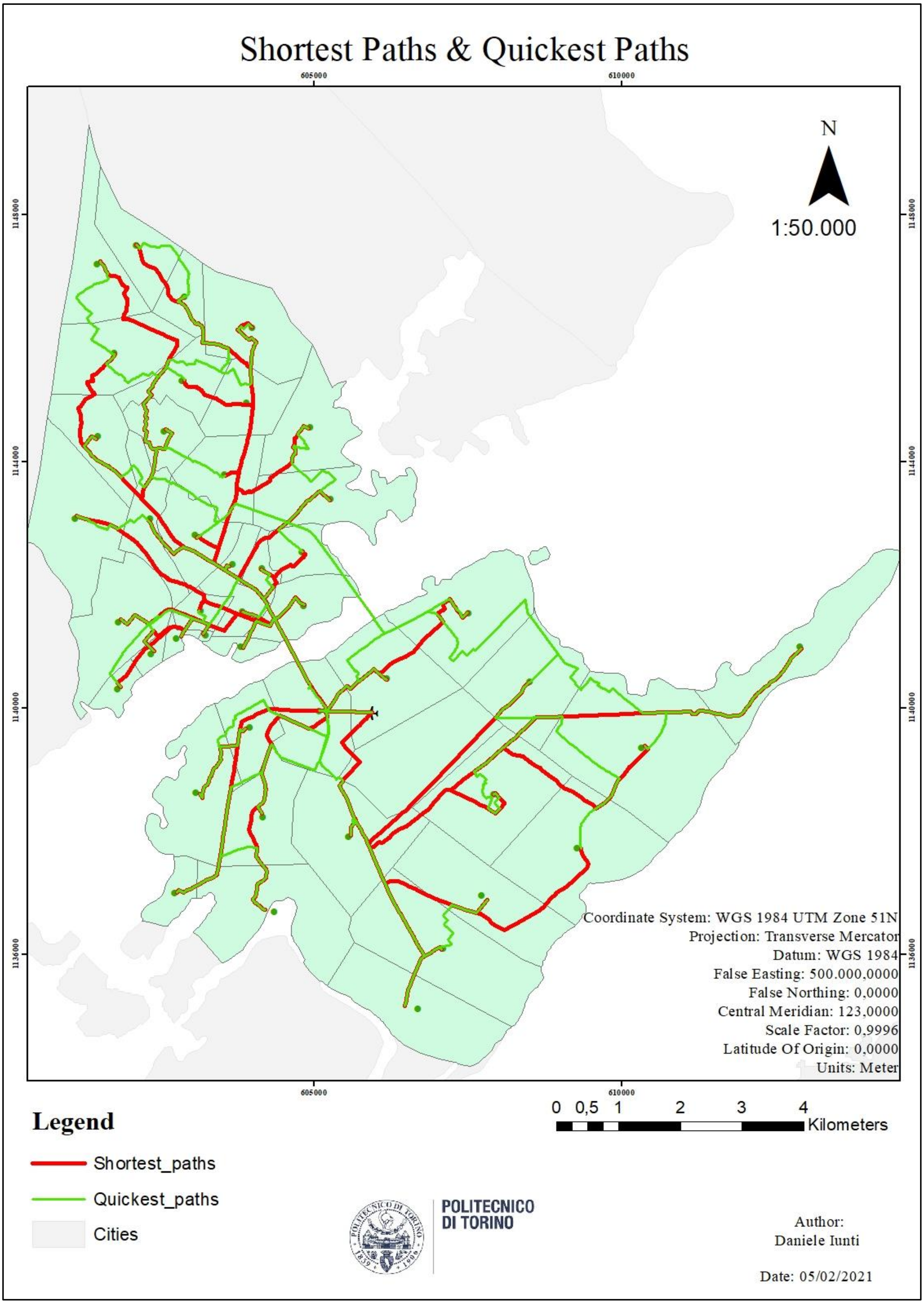

*Map 3: Road Network*



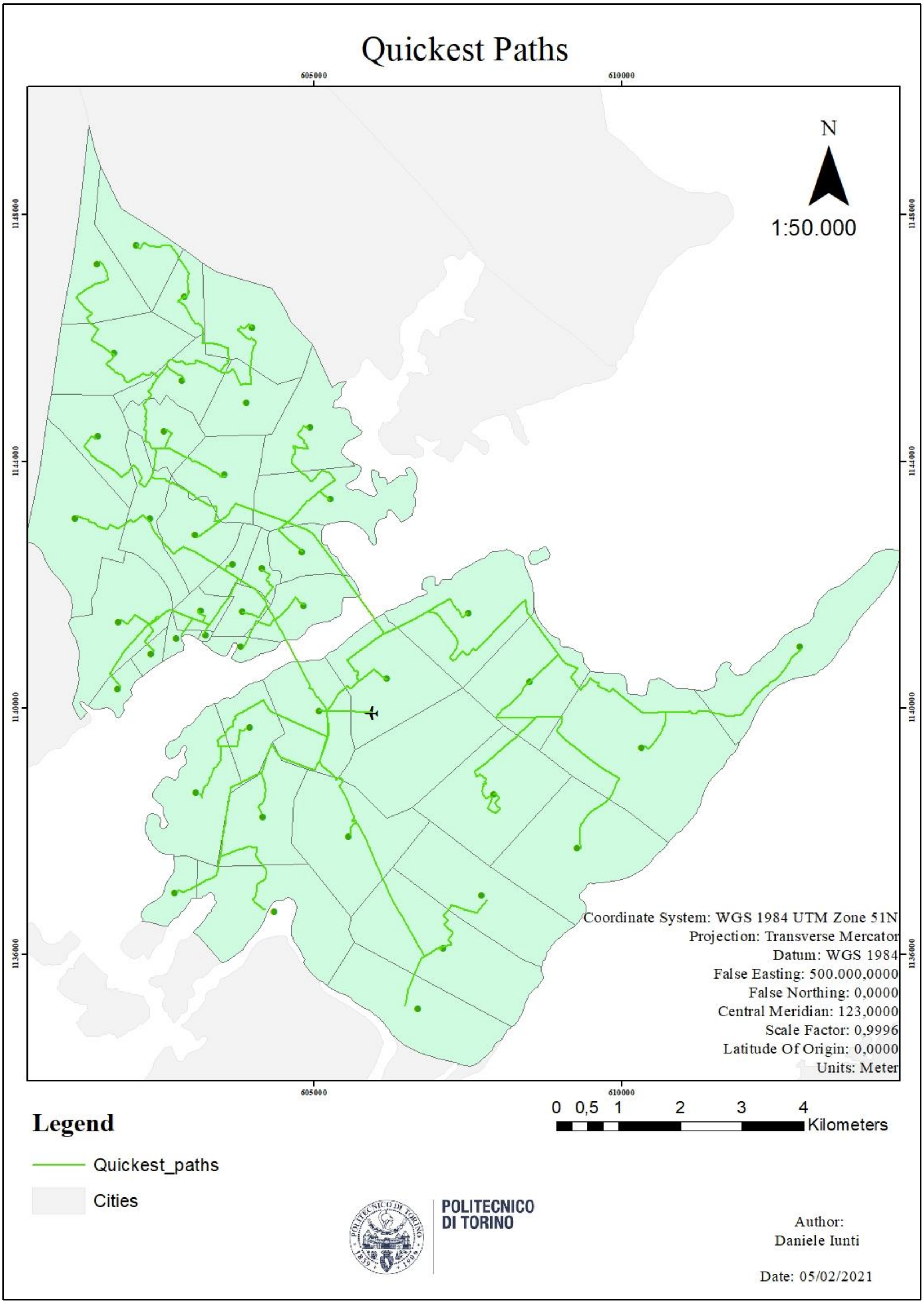

***Map 4****: Traffic Analysis Zones and Baranagays*



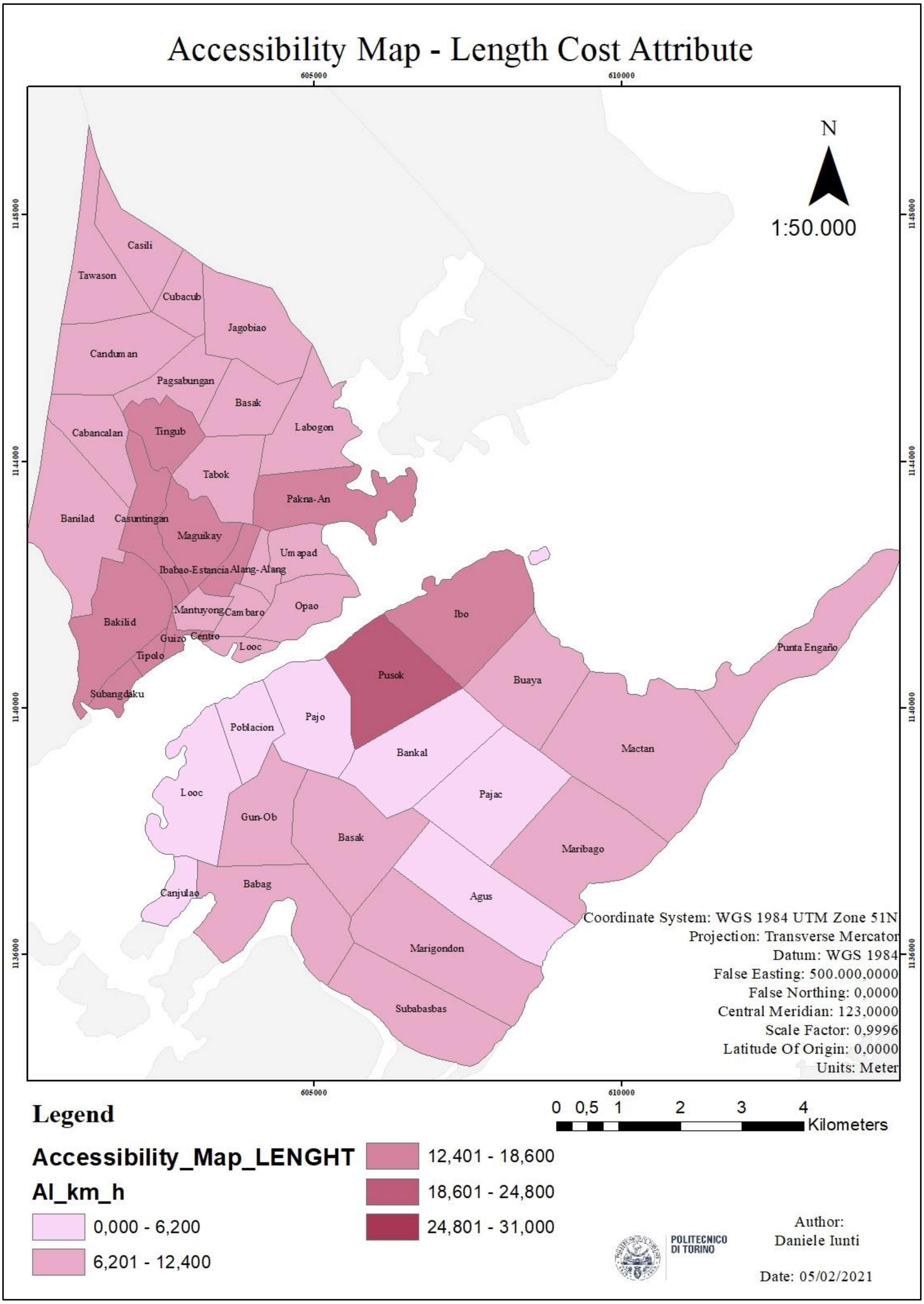

***Map 5**: Network Analyst: Shortest itineraries*



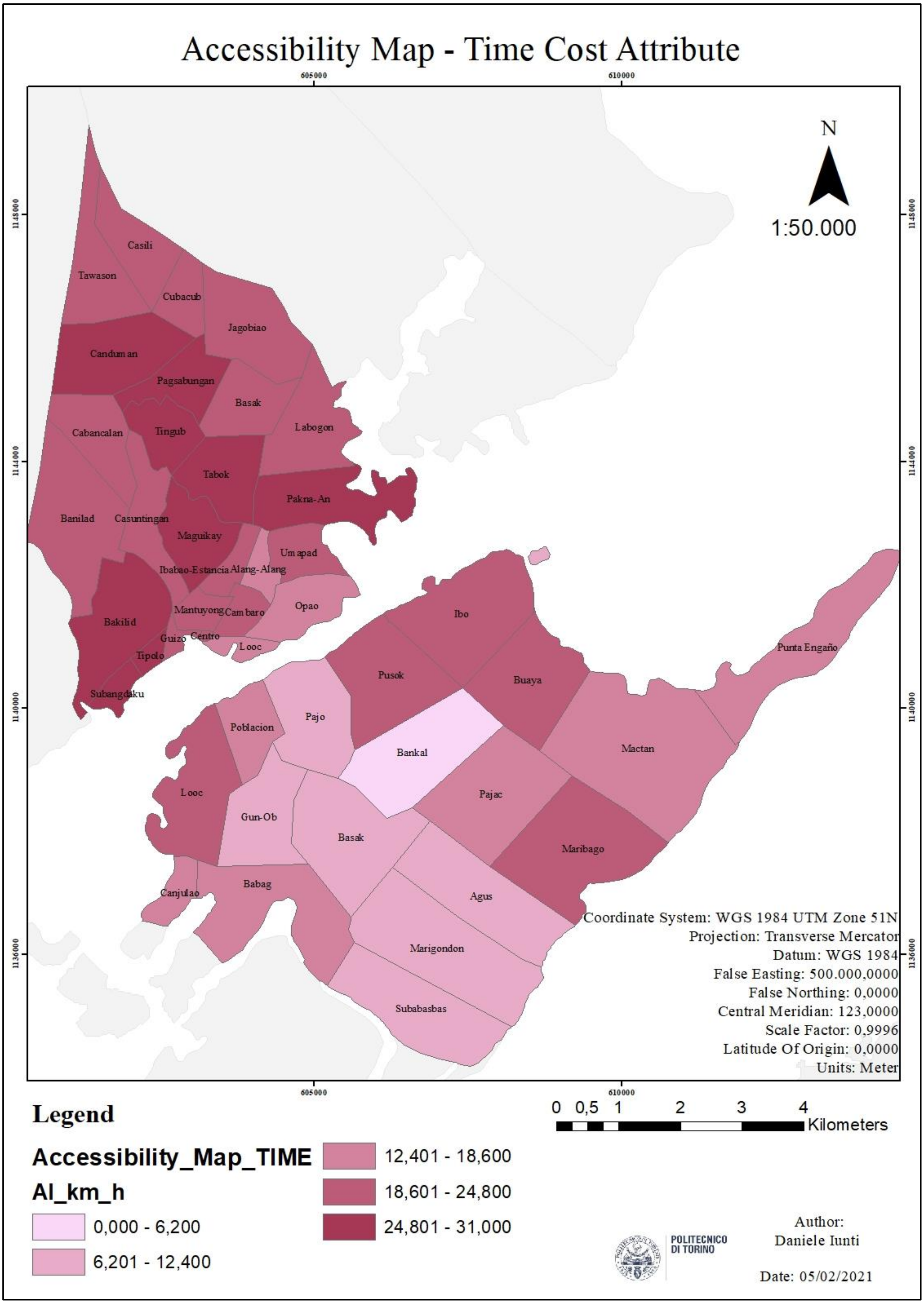

*Map 6: Network Analyst: Comparison shortest Paths and Quickest Paths*



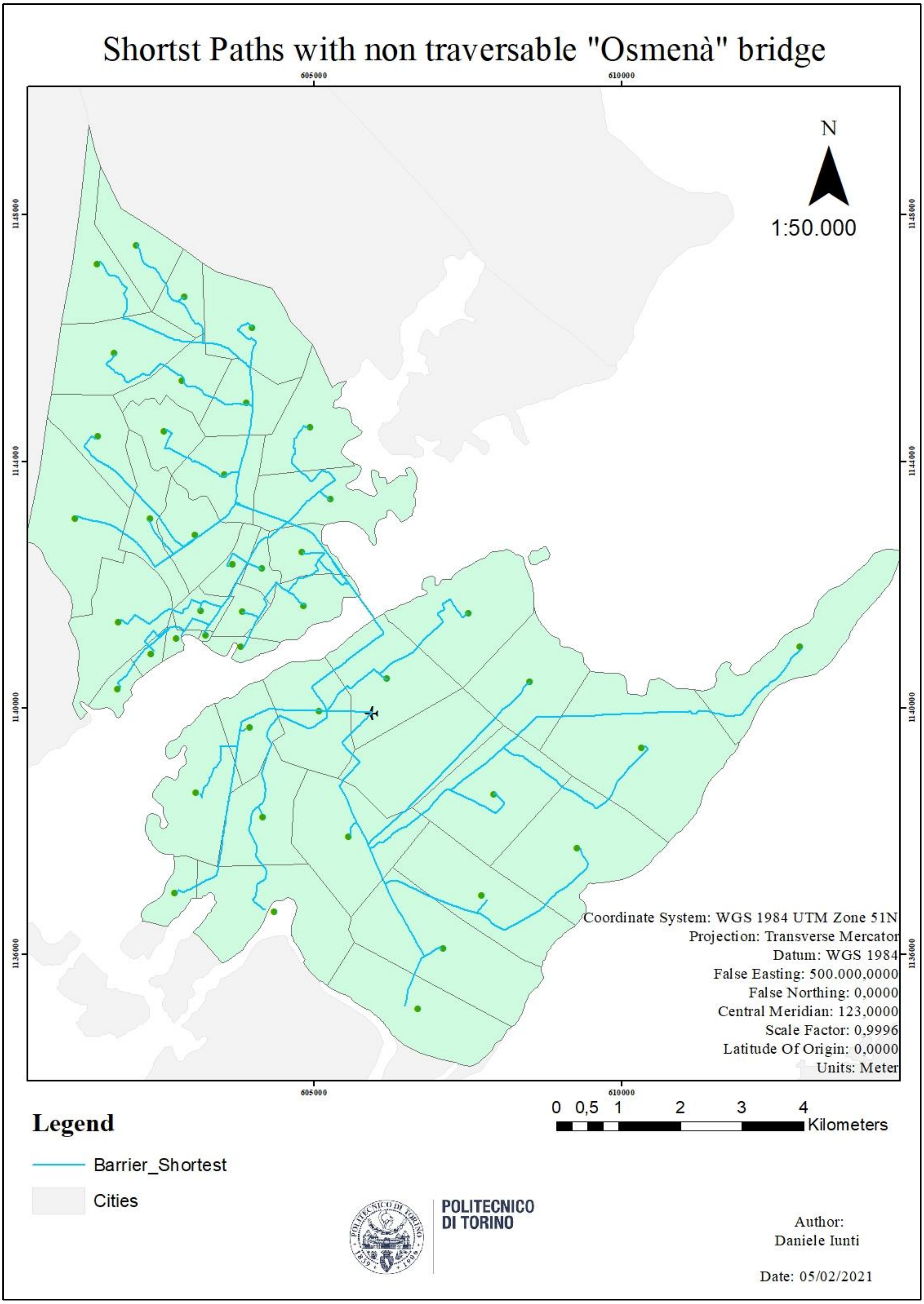

***Map 7**: Network Analyst: Quickest itineraries*



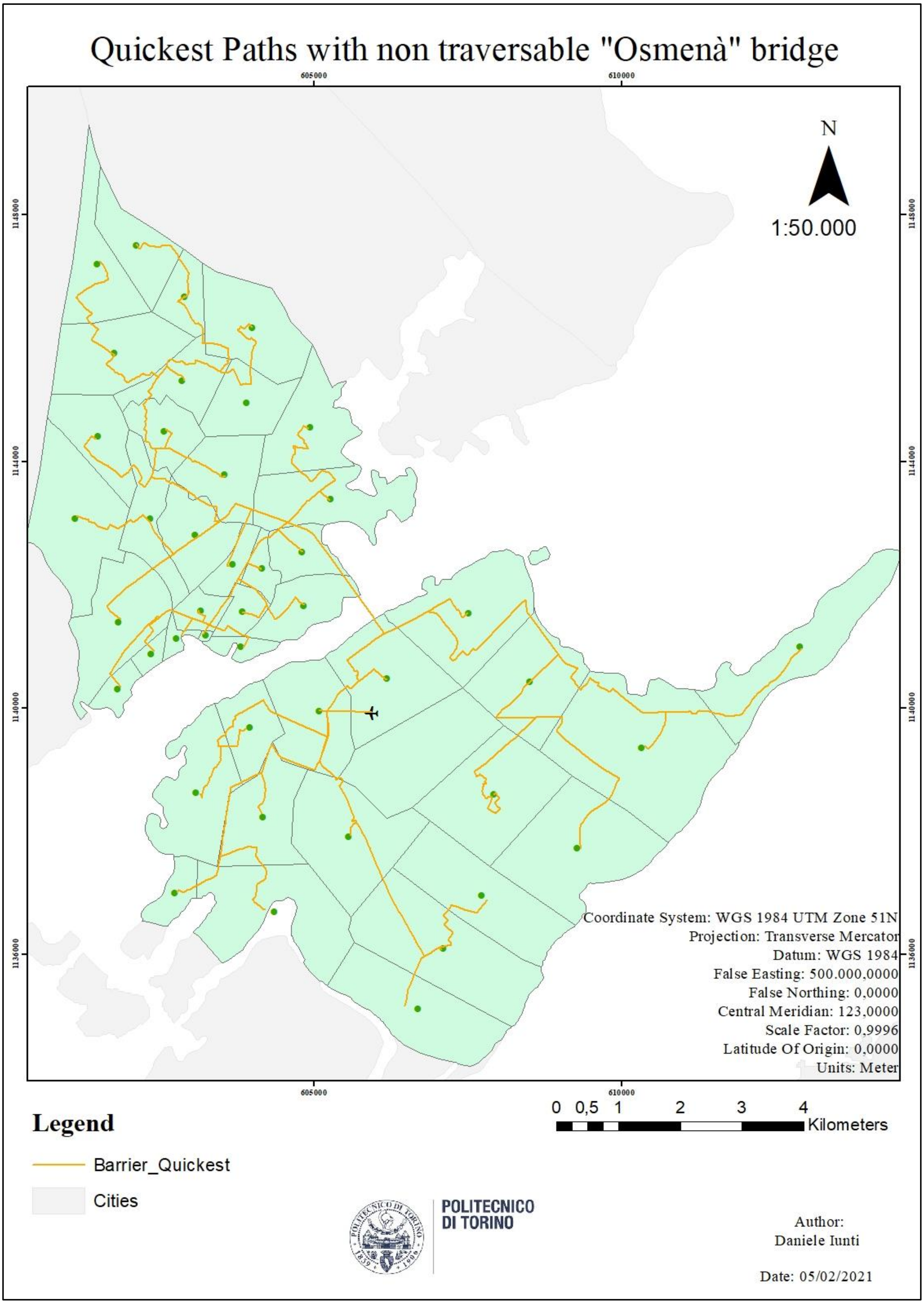

*Map 8: Accessibility analysis: Map by Travel Length cost attribute*



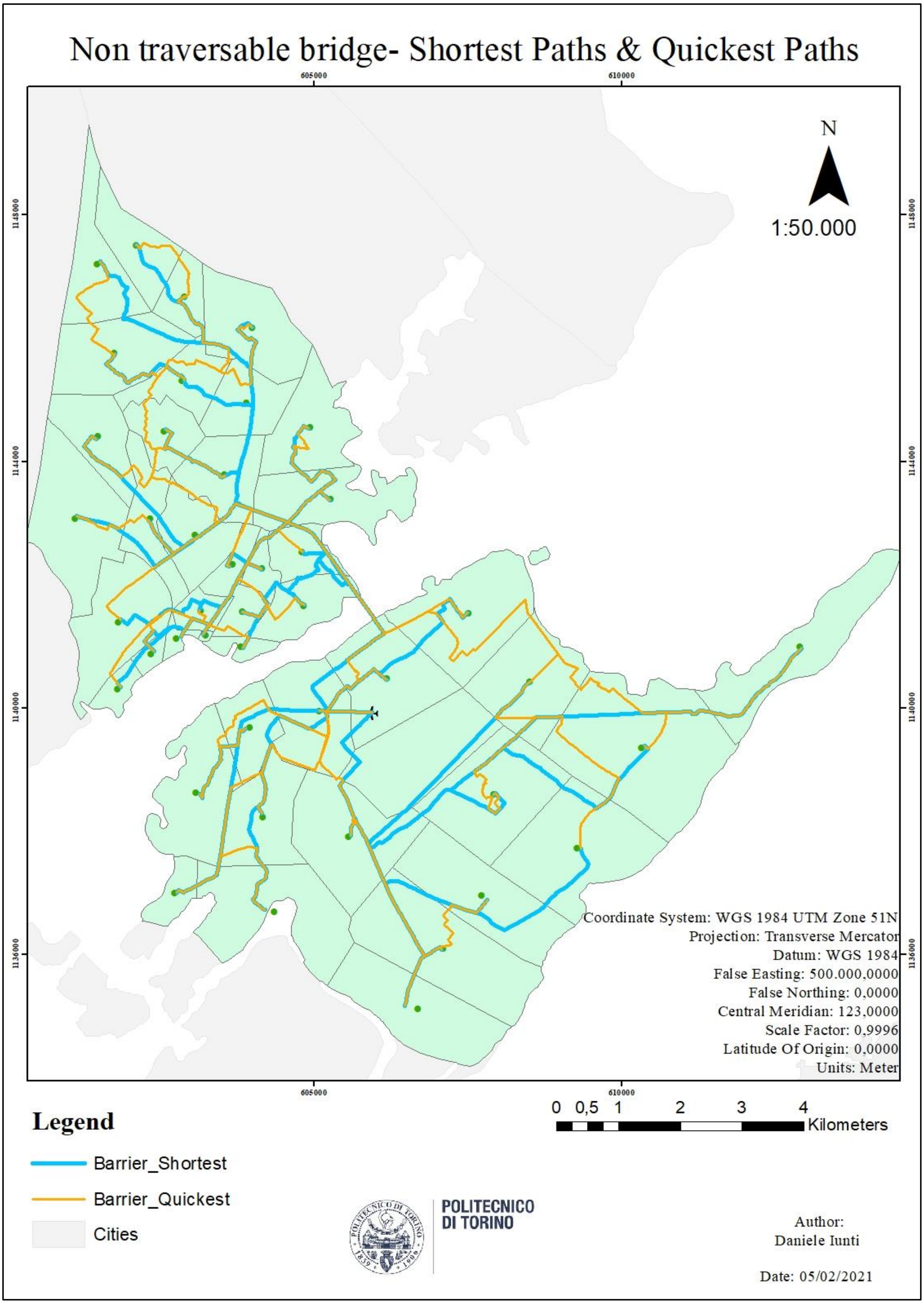

***Map 9**: Accessibility analysis: Map by Travel Time cost attribute*



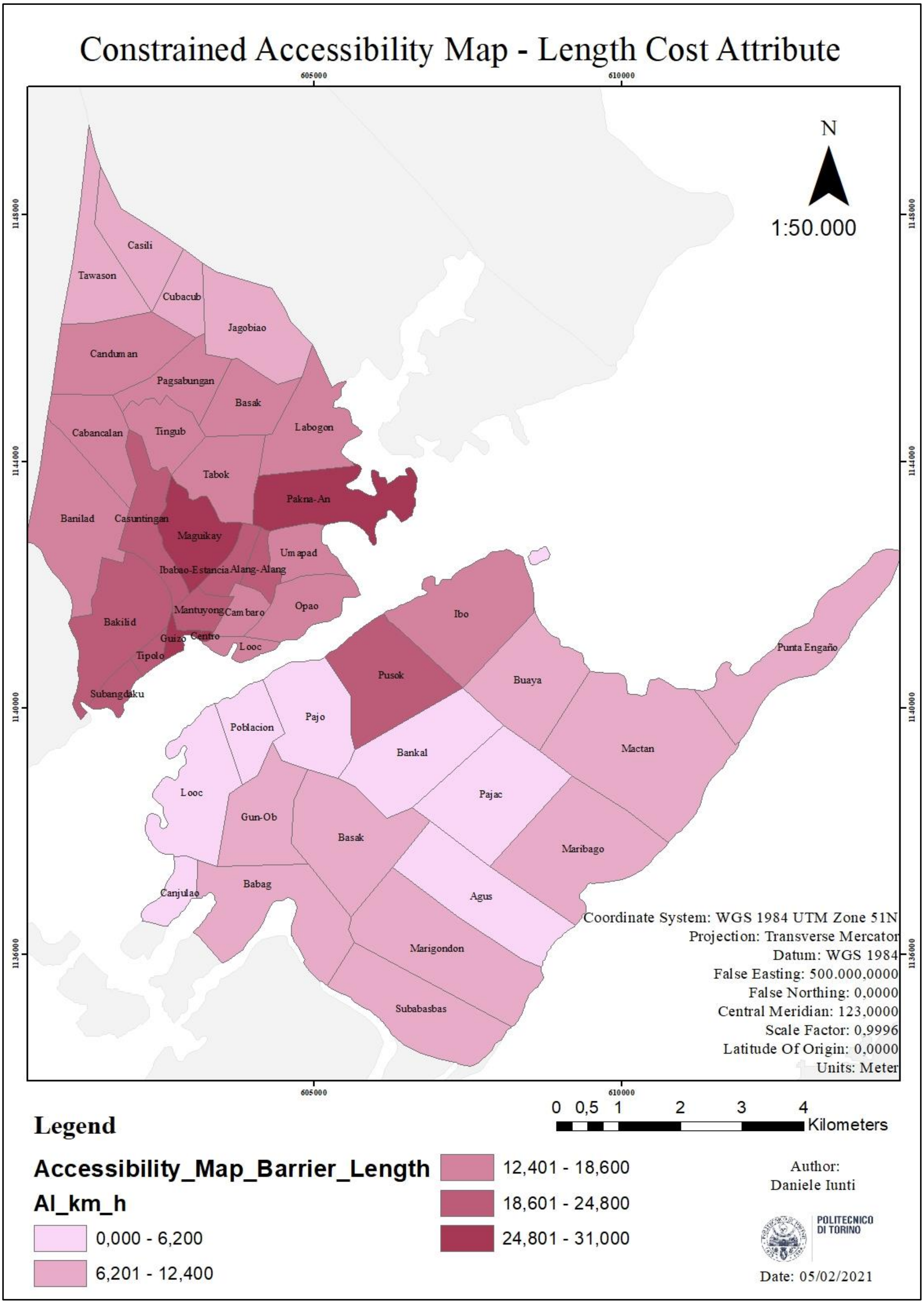

***Map 10**: Network Analyst: Shortest itineraries in constrained traffic conditions*



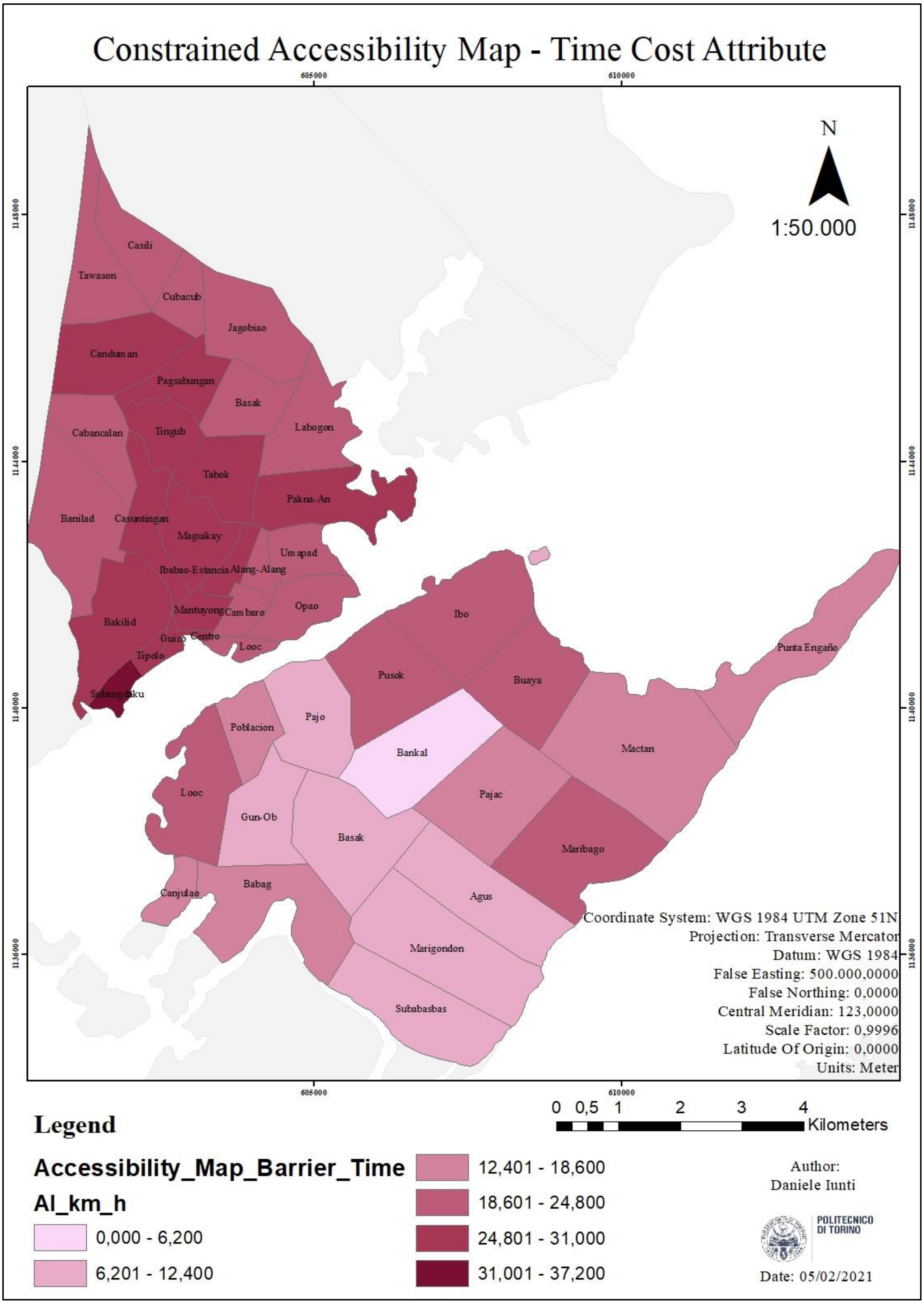

***Map 11****: Network Analyst: Quickest itineraries in constrained traffic conditions*



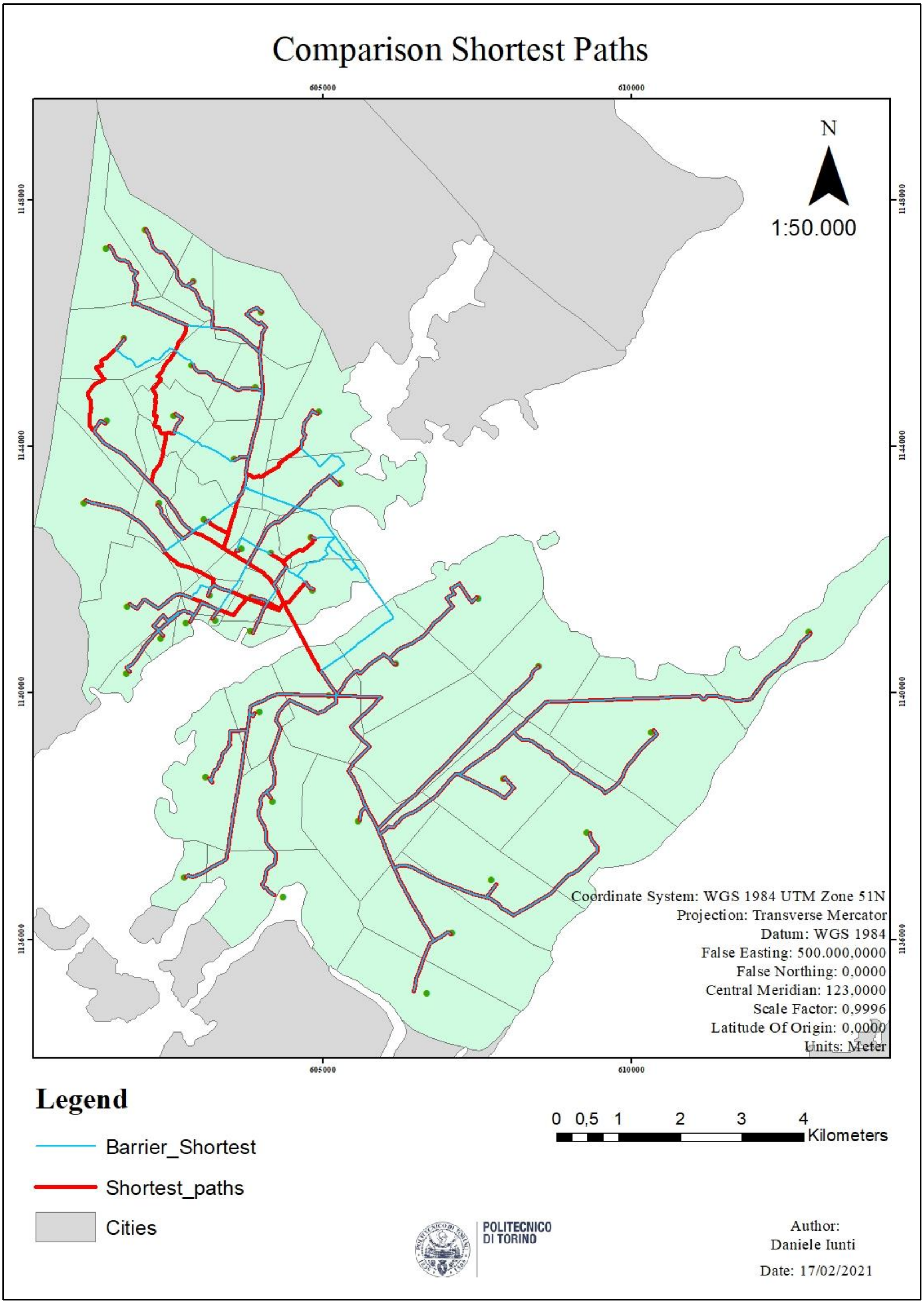

***Map 12****: Network Analyst: Itineraries comparison in constrained traffic conditions*



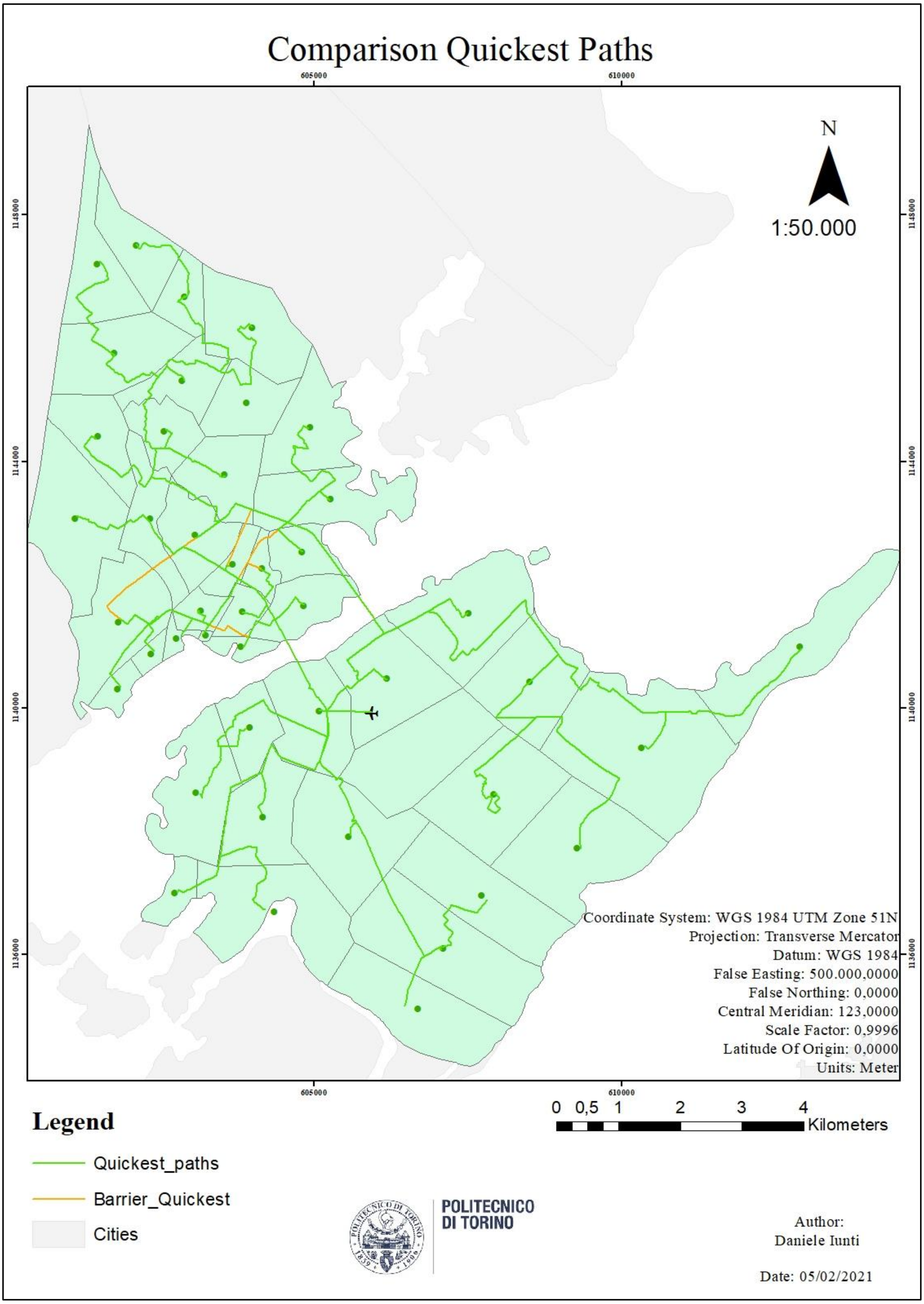

***Map 13***: *Accessibility analysis: Map by Length in constrained traffic conditions*




***Map 14**: Accessibility analysis: Map by Time in constrained traffic conditions*

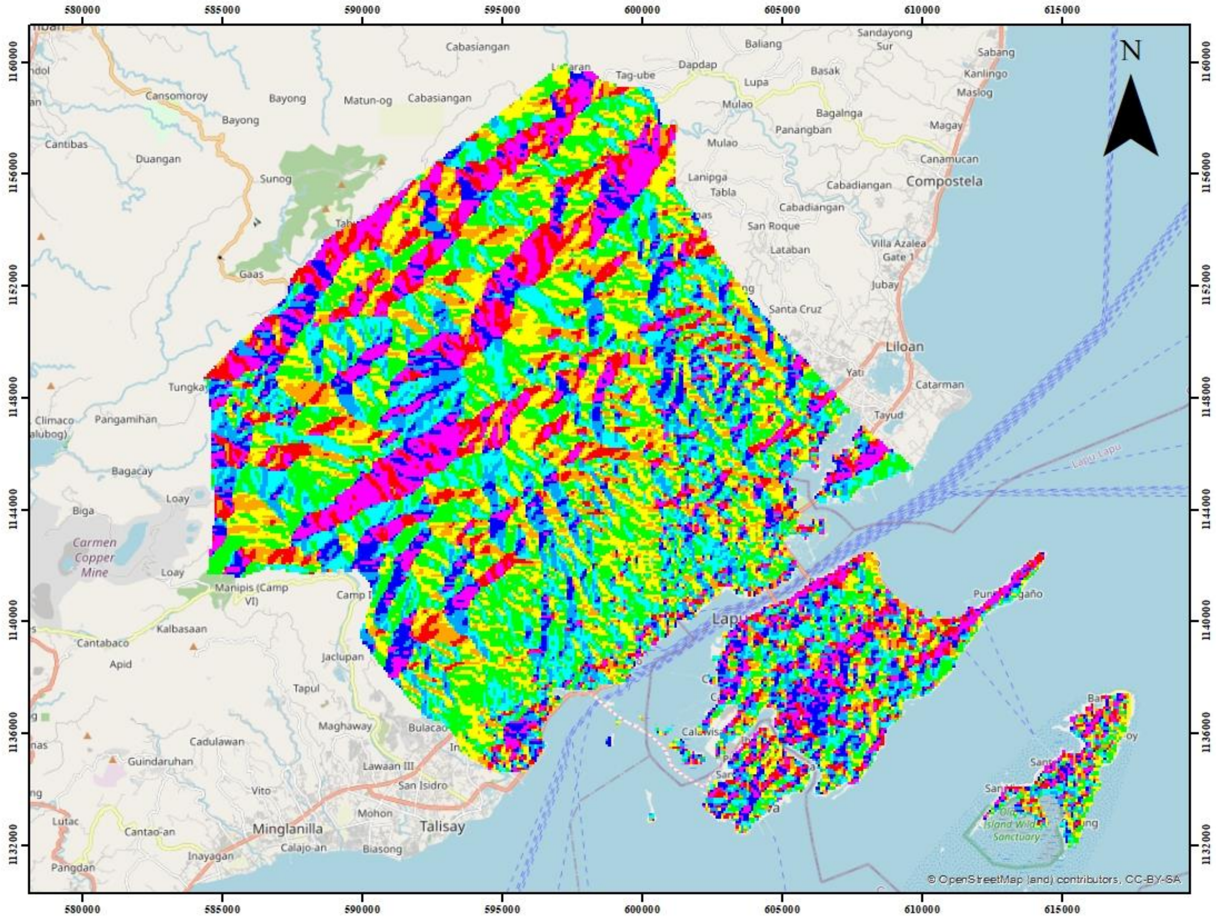



***Map 15**: Network Analyst: Shortest itineraries comparison in different traffic conditions*




***Map 16**: Network Analyst: Quickest itineraries comparison in different traffic conditions*

# Aspect Map




0 1,5 3 6 9 12 Kilometers

1:150.000

**Legend:**
**Cells slope degree**

- North (0-22.5)
- Northeast (22.5-67.5)
- East (67.5-112.5)
- Southeast (112.5-157.5)
- South (157.5-202.5)
- Southwest (202.5-247.5)
- West (247.5-292.5)
- Northwest (292.5-337.5)
- North (337.5-360)

Coordinate System: WGS 1984 UTM Zone 51N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500.000,0000
False Northing: 0,0000
Central Meridian: 123,0000
Scale Factor: 0,9996
Latitude Of Origin: 0,0000
Units: Meter

POLITECNICO DI TORINO

Author:
Daniele Iunti

Date: 09/03/2021

***Map 17**: Aspect map*

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