UNIVERSITY OF GOTHENBURG
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**Master Thesis Double Degree Program**

**in Innovation and Industrial Management**

# Smart Cities as Ecosystems

What Will be the Impact of 5G?


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ACC: Adaptive Cruise Control

AR: Augmented Reality

FTK: Fist To Know

Gpbs: Gigabit per second

GPS: Global Positioning System

GSM: Global System for Mobile Communication

HSDPA: High Speed Downlink Packet Access

HSUPA: High Speed Uplink Packet Access

ICT: Information and Communication Technology

IoT: Internet of Things

IT: Information Technology

LoRa: Long Range

LTE: Long Term Evolution

M2M: Machine to Machine

Mbps: Megabit per second

MIMO: Multiple-Input and Multiple-Output

mmWave: millimeterWave

Ms: millisecond

Qos: Quality of Service

UMTS: Universal Mobile Telecommunications System

UOS: Urban Operating System

VR: Virtual Reality

# ABSTRACT

Smart cities are often defined in the literature as business ecosystems, in the same way trials have been conducted over the years to apply 5G technology to the various smart solutions that make up this business ecosystem. Despite these obvious correlations, there is a lack of qualitative studies regarding the application of business ecosystem theory to smart cities and the effects of 5G technology on smart solutions. Therefore, the researcher decided to fill this gap by carrying out a study in this regard. In particular, the researcher focused on the research of possible bottlenecks (a founding element of business ecosystem theory) in the current use of ICTs for delivering smart solutions and whether or not 5G is able to solve them.
The qualitative study therefore concerns a case study limited to the geographical area of the city of Gothenburg, in which the researcher studied whether several companies and organizations developing smart solutions within the smart city ecosystem find bottlenecks in the current use of ICTs and whether 5G can solve these bottlenecks.

The findings show how the companies and organizations interviewed are satisfied with the current performance of the ICT tools used to implement smart solutions. Nevertheless, in the future, when the scale up of smart projects and the implementation of smart solutions will take place, the current performance of the ICTs used will not be sufficient. Therefore, companies and organizations will witness future bottlenecks. These bottlenecks will concern both the mobile connectivity and the smart solutions domain.
Thanks to its features, 5G technology will be able to solve such bottlenecks. But this will happen only if three limitations are overcome: the lack of a sufficient infrastructure to support the development of 5G technology, a reduction in the costs of such technology and a historical era willing to accept the use of such technology.

**Keywords:** Smart City, Smart Solutions, Business Ecosystem Theory, Bottlenecks, 5G, 5G applications

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Göteborg, 1st June 2020

*The Double Degree experience was unique, satisfying and full of emotions that will accompany me for the rest of my life. Writing this Master Thesis has been a stimulating and challenging path, which has helped me to grow as a student and as a person. I could not have wished to conclude this experience in a better way.*

*The first acknowledgment goes to First to Know and in particular to Per Östling. His unique way of seeing things, his commitment and dedication to bridging the gap between companies and innovation were a source of learning and help in writing this paper. Thanks to his example I learned to see things from a different angle.*

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# 1 Introduction

*The purpose of this chapter is to introduce the topic of research. In particular, the introductory section of the thesis includes a project outline chapter, followed by the research project background, the research problem, the research purpose and the research question. Then the limitations that the researcher found during the research project and the layout of the thesis are explained.*

## 1.1 Project Outline

This Master Thesis project was born thanks to the collaboration between the researcher and the Swedish consultancy firm FIRST TO KNOW (FTK) located in Gothenburg, Sweden. The aim of FTK is to enable organizations to reach their maximum potential and to bridge the gap between business and academia in order to facilitate the innovation process in which many companies are involved. Thanks to this collaboration, the researcher was able to benefit from the network provided by FTK advisor Per Östling.
The researcher took part in the "The Space" project, set up by FTK, through which he was able to benefit from an Innovation Hub where he could interact with several companies that presented topics related to innovation and business transformation, which were a fundamental cue in the process of deciding the topic to be dealt with by the researcher. The continuous exposure to the ideas of the companies that have contributed with their interventions at the Innovation Hub and the support of FTK, allowed the researcher to focus on a topic of interest that could match the mission and vision of the Swedish consultancy firm.
Since the researcher participated in the Double Degree program between the University of Göteborg and Luiss Guido Carli in Rome, the contribution of the Italian relator was of fundamental importance in order to realize a valid work that could contribute from an academic point of view.

## 1.2 Background

The history of mobile connectivity began in 1980 with the introduction of 1G technology and the ability to make calls through the analog signal (Panwar et al., 2016). Over the last forty years, several generations of mobile communications technologies have followed one another, up to 5G technology. The latest arrival of mobile networks will not only take connectivity to another level, through coverage improvements, latency reduction and energy savings (Andrews et al., 2014), but will also bring epochal changes in different industrial sectors such as healthcare, automotive, public transport, energy, manufacturing, entertainment, and will make possible the realization of smart cities (Chandramouli et al., 2019). A smart city can be defined as a city where all major infrastructures are interconnected (Hall, 2000) and according to the European Union a smart city focuses on energy efficiency, renewable energy use and zero impact mobility (Lazaroiu & Roscia., 2012).

Beyond the definitions a fundamental feature of a smart city are the different actors that collaborate in the creation of a value proposition, for this reason a smart city can be defined as a business ecosystem, i.e. a set of partners that must work together to make a focal value proposition (Adner, 2017). Smart cities are seen as an ecosystem rather than a marketplace. There are many examples of projects that adopt this vision, in different countries of the world (Alusi et al., 2011). The PlanIT Valley project, focused on the realization of a smart city in Portugal, aims at "creating an ecosystem of large and small company partners that will focus on creating products and services for sustainable urbanization" (Alusi et al., 2011, p. 12). Similarly, in studies carried out on the analysis of the business models of the various players in smart cities, it was stressed that a smart city is an ecosystem. Díaz-Díaz et al., (2017) in their case study on the smart city of Santander in Spain, highlighted that a city to define itself as smart must necessarily consist of an ecosystem composed of different stakeholders from the private and public sector. These stakeholders must interact with each other and with the various urban components in order to make cities intelligent and sustainable. Thanks to the examples that have been provided, and many others that exist in the literature, it is possible to note that the theory of business ecosystems is closely linked to the smart city concept.

The social phenomenon of smart cities is also closely linked to the development of 5G technology. In fact, there are cases in which trials have been launched with the development of 5G technology within cities in order to make urban ecosystem services smarter and more efficient. Two examples are the Italian cities of Prato and L'Aquila, which have been test fields for 5G technology. In particular, within the project for the implementation of 5G technology in the urban context involving these two cities, among the various use cases for the implementation of 5G technology most of them concerned smart solutions that could have an impact on the citizen's life. These include e-health, smart grid, IoT and smart sensors, city surveillance, smart safety, smart mobility, augmented and virtual reality and structure monitoring for buildings (Marabissi et al., 2019). Another case of application of 5G technology in a smart city is the one inherent to the city of Alba Iulia in Romania, where 5G technology has been used for the implementation of the intelligent lighting use case (Oproiu et al., 2017). Another example of a project in which 5G technology plays a role within the smart cities world is LuxTurrim5G, where 5G technology is used to implement the smart light pole system in order to improve the lighting of smart cities (Hemilä & Salmelin., 2017). There are therefore many projects involving the use of 5G technology to improve the value proposition of the various actors in a smart city.

## 1.3 Research Problem

The theory of ecosystems, in the last thirty years has acquired a relevant place among the tools utilized for studying the social and business realities that surround us. At the same time, smart city has become a reality on everyone's lips, in fact the world has realized that our cities must grow not only in size, but also in the quality of services and infrastructure made available to citizens.

In the literature, smart city is repeatedly defined as an ecosystem and trials to implement 5G solutions within cities are frequent. However, there are no studies that have applied the principles of business ecosystem theory to study the implementation of 5G technologies for delivering smart solutions. Following this reasoning, the researcher decided to carry out this research in order to fill the existing gap.

Another problem that has not been solved is to identify practical uses of 5G technology for the end consumer. There is evidence in literature of how 5G technology could revolutionize the reality around us and countless are the areas in which this technology could improve our lives. Despite this, concrete applications that could have a significant impact on the final consumer have not yet been found.

Another problem concerning 5G technology regards the use of ecosystem theory. Technologies are often studied according to the speed with which they will replace the previous ones and very often it is stressed that for them to be successful in the market it is necessary to study the ecosystem that is created around technological innovation (Adner & Kapoor., 2016). Even if in this case, in which thanks to the application of the ecosystem theory all the actors involved in the innovation process are taken into consideration, technology remains the main protagonist and the study is aimed at making technological innovation successful on the market. In this way the focus on the technological applications for the final customers is not taken into consideration.

## 1.4 Research Purpose

Taking into account the background and the research problem, the purpose of this research can be outlined as follows. The researcher intends to apply the business ecosystem theory to the social phenomenon of the smart city, focusing in particular on the effect of 5G technology on the smart solutions that are applied. In particular the researcher will find out if there are bottlenecks in the use of current ICTs (information and communication technologies) that companies use to deliver smart solutions and if these bottlenecks can be solved through the use of 5G technology. The researcher considered it important to carry out a research project that could study 5G technology in a concrete and not random way, putting at the centre of his research interest the goodness of technological innovation at the service of the consumer and not of the market. Therefore, the theory of ecosystems, if applied to social phenomena such as smart cities, can allow to study how and if 5G technology will impact on citizens' lives in a concrete way.

## 1.5 Research Question

Taking into account the background, the discussion of the problem and the purpose of the study, the research question can be formulated as follows:

*What bottlenecks in the smart city ecosystem, if any, can be overcome with 5G technology?*

In order to answer the question, the researcher had to break down the main research question in two sub-questions:

*Which are the bottlenecks of the ICT tools for delivering smart solutions?*

*To what extent can these bottlenecks be solved through 5G?*

## 1.6 Research Boundaries

The research work had to be subject to certain limitations during its development. The main limitation is of a geographical nature. In fact, since the researcher carried out his research work in Sweden, it is difficult to extend the results to other countries outside the Scandinavian country because each nation is at different stages in the implementation of 5G technology and smart cities.

Moreover, due to time constraints and extraordinary events such as the spread of the COVID-19 pandemic, the researcher found a limit in the number of interviews that were carried out (**see Empirical Findings**). Nevertheless, the researcher is satisfied with the number of interviews he was able to carry out and believes that the data collected helped to answer the research question in a comprehensive and timely manner.

Another of the limitations to which the researcher went against was the fact that 5G technology and its practical applications are still quite unexplored in many areas. Moreover, it is not automatic that people involved in the development of smart solutions within their companies have a detailed knowledge of 5G technology. Therefore, the researcher tried to solve the problem by addressing both practitioners involved in the development of smart solutions and 5G technology experts in order to have a complete picture of the situation.

## 1.7 Thesis Disposition

The work of Master Thesis has been realized following a layout characterized by the presence of six different areas:

- Introduction
- Literature Review
- Methodology
- Empirical Findings
- Data Analysis
- Conclusions

In the introduction section, the researcher informed the reader about the essential characteristics of the research project. In particular, the researcher provided the reader with the background of the research work, the research question, the research objectives/research purpose, and the limitations faced during the course of the research project.

In the literature review section, the researcher built the theoretical framework underlying the research project. In particular, this section is divided into three macro-areas. One concerning the technical characteristics of 5G technology and its business applications, one concerning the theory of business ecosystems, and one concerning smart cities. In the smart city section, the researcher talked about the characteristics of the smart city as a business ecosystem and the influence that 5G technology can have on the smart solutions that make up this ecosystem. For this reason, the last macro-area, besides introducing a new topic, is the link between the two previous macro-areas.

In the methodology section, the researcher explained what choices were made to fulfill the research. In particular the research design, research strategy and research methods were outlined. In this section, emphasis was placed on the choice of respondents (sampling) and the collection of primary data (interviews) and secondary data (which constitutes the literature review). In addition, the researcher provided information regarding the realization of the data analysis and the criteria that were followed to make the research qualitatively satisfactory.

In the empirical findings section, the researcher carried out a detailed transcription of the interviews after they were carried out. The careful and meticulous transcription ensured that the research was based on a solid foundation of primary data collection.

In the data analysis section, the researcher analyzed the primary data through the coding process and compared them with the secondary data in order to elaborate categories and themes for answering the research question.

In the conclusions and recommendations section, the researcher reported his answers to the research question and suggested possible recommendations for future research on the topic in his current research work.

There are also three other sections, the abstract, the acknowledgments, the bibliography and the appendixes. In the abstract there is a summary of the research work, in the acknowledgment section the researcher expressed his greetings, in the references there are all the articles/books/studies to which the author referred during the work , and in the appendixes there are the interview guide and the coding process utilized in the data analysts. Other sections are the list of figures, the list of tables and a list of abbreviations.

# 2 Literature Review

*In this chapter we present the theoretical background on which the research is based. The literature review is divided into three different parts. In the first section a general review is presented on what are the characteristics of 5G technology. In the second section the business ecosystem concept, how it can be studied, and its components are presented. The third part illustrates the concept of smart city as a business ecosystem, its components and the effects that 5G technology can have on this ecosystem in particular.*

## 2.1 About 5G

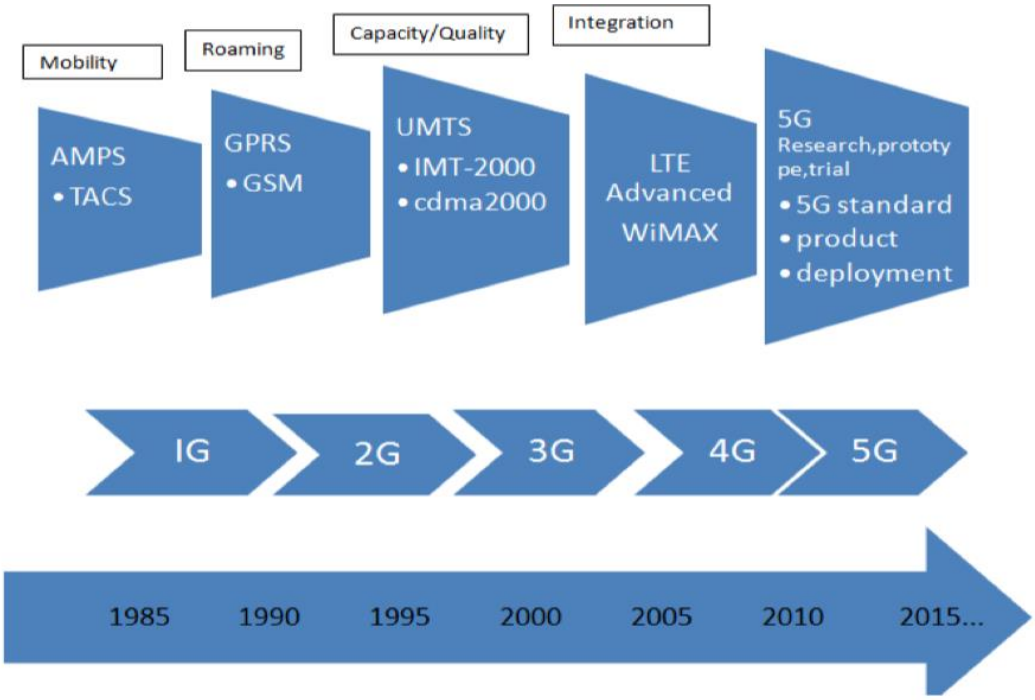
Since Guglielmo Marconi paved the way for modern wireless communication systems, a long journey has been made in the world of communication. Over the years, wireless technologies have improved in data rate, mobility, coverage and efficiency (Gupta & Jha., 2015).
5G, the latest version of cellular wireless mobile network, will enhance the quality of user experience, reduce the time needed to send data and decrease power consumption (Hossain & Hasan., 2015).

### 2.1.1 History in brief

Every 10 years we have witnessed the introduction of a new generation of technology in the field of mobile traffic. In 1981 the first 1G systems were introduced and in 1992 we witnessed the introduction of 2G. In 2001 we benefited from 3G which revolutionized our world by allowing the development of the first smartphones. The development of 4G systems started in 2002 and 4G technology became a standard around 2010 (Singh & Singh., 2012).

1G was the first generation of wireless cellular technology and it utilized analogical radio signals to favour communication. This technology enabled the introduction of the first mobile phones. GSM (Global System for Mobile Communication) or 2G consisted in the first move towards the evolution of the primitive devices, delivering connectivity for voice communication. Another step in the evolution of the mobile network technology was the General Packet Radio Service (2.5G), which provided mobile data communication in a period in which we were witnessing the dawn of internet and its full potential had to be already discovered. UMTS (3G) was created to be a technology that could guarantee different services (voice, internet data, video) through the same network, but it got a real boost with the addition of HSDPA and HSUPA (3.5G) to offer fast mobile data services. With the implementation of 3G and through 3.5G the first wireless broadband was delivered to the market. Thanks to the introduction of 3G, we have experienced the arrival on the market of smartphones, which have brought multi-services on the same device and have revolutionized the way we live. LTE(4G) which is the current generation, provided the first example of mobile broadband (Tudzarov & Gelev., 2017).

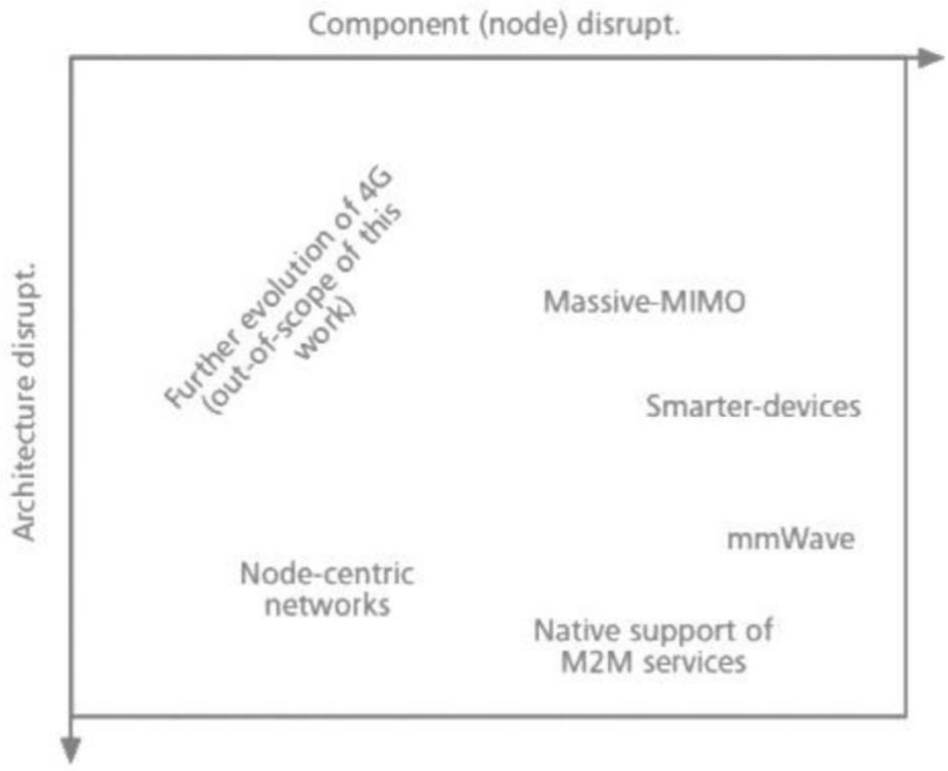
Figure 1: Mobile Cellular Network Evolution Timeline – (Sood & Garg, 2014)



### 2.1.2 Evolution or Revolution?

5G technology will improve the way mobile phones are used through the exploitation of much higher bandwidth and capacity. 5G is going to provide a wider coverage and a much higher data transmission capacity than the previous generations of broadband cellular networks. 5G systems can be evolutionary and revolutionary: in the evolutionary view, 5G systems will enable highly flexible networks and improve the performance of already existing 4G applications. In the revolutionary view, 5G is seen as an extremely revolutionary technology that will provide a worldwide limitless interconnection (Singh & Singh., 2012). To understand whether 5G will be an evolution or a revolution it is essential to understand what the emerging technologies in the field of 5G connectivity are. It is also fundamental to study what are the changes these technologies will have to endure in order to support the rise of 5G technology. Regardless of the technologies under examination, it is known that the major changes to which they will be subjected will concern network node and architecture levels (Al-Falahy & Alani., 2017). Boccardi et al., (2014) classified the impact on five possible disruptive technologies taking into account the changes they could experience both at network node and architectural level, thanks to the utilization of the Henderson-Clark Model.

Figure 2: Impact of the different technologies at an architectural and component level – (Boccardi et al., 2014, p.75)



Depending on the impact that these technologies will experiment on node and architectural levels, the authors have identified four different types of changes that technologies will face:

- *Evolutions in design*: when there are small changes at the node level and architectural levels
- *Component Changes*: when there are disruptive changes at network nodes level
- *Architectural Changes*: when there are significant changes in architecture
- *Radical Changes*: when there are disruptive changes at both the architecture and node level

The five potentially disruptive technologies that could experience changes in both architecture and node level are:

- *Node-centric networks*: The change in information flows will provide more complete routes and a very low latency. Thanks to these innovations there will be severe changes in the architecture system, or as we pointed out before there will be architectural changes.
- *Massive MIMO*: Massive multiple-input multiple output (MIMO), which involves the use of several antennas to fill the need to have different network frequencies at the same time depending on the device we are using, will require a major change in the design level of network nodes, thus generating important component changes.
- *Smarter devices*: Will require changes in the architecture, developing smarter devices means entering in a new era of connectivity, the so called D2D (device to device) era.
- *Millimeter wawe (mmWave)*: the signal will be increased in frequency and the bandwidth will be expanded. In this field there will be changes both at architectural and node level, implying radical changes in this kind of technology and a strong implication for 5G.
- *Native support for machine-to-machine (M2M) communication*: that is, the origin of Industry 4.0. This will entail low data-rate services and low-latency data transmission. New ideas will be brought at both architectural and component level. So, radical changes will be experienced.

### 2.1.3 5G Requirements

The applications of 5G will be varied and vast, starting from augmented reality, to massive IoT, to 4K multimedia content playback, to critical IoT. Andrews et al., (2014) stress how in order for all these applications to become reality, there are requirements that the 5G network must meet: *data rate*, *latency* and *energy & cost*.

#### 2.1.3.1 Data rate

Regarding the data rate, engineers are convinced that the development of the 5G network will lead to a considerable increase in data traffic, and the ability to support this huge increase in capacity will be one of the main requirements of the new technology. According to Andrews et al., (2014), three different metrics are taken into account to calculate the data rate:

- The *aggregate data rate* or *area capacity*, which consist of the amount of data that the network can support and is calculated in bits/s per unit area. The common opinion is that the data capacity processed by the 5G network will have to increase by 10^3 times compared to the current 4G network.
- The *edge rate* or *5% rate* is the worst network coverage a user can experience when using a mobile phone. It occurs primarily in areas outside of cities and away from mobile stations. 5G should bring edge rates in a range between 100 Mbps and 1 Gbps. This is a very ambitious goal that 5G sets itself as the current edge rate of 4G is around 1Mpbs.
- The *Peak Rate* is the best data rate that a consumer can experience, normally consists of a fictitious number that is unlikely to be reached and experts place it around 10 Gbps (Andrews et al., 2014).

#### 2.1.3.2 Latency

Another fundamental aspect that we have to take into account regarding 5G is latency: the time interval between the stimulation and response. Parvez et al., (2018, p. 3099) underline that regarding 5G: "Latency is highly critical in some applications such as automated industrial production, robotics, transportation, healthcare, entertainment, virtual reality, education and culture". Andrews et al., (2014) regarding latency explain how the current latency of 4G technology is in the order of 15 ms, while 5G should support a latency of 1ms.

#### 2.1.3.3 Energy & Cost

Another requirement 5G technology should meet is the downfall of energy consumption and cost. In particular mmWave spectrum should be less expensive per Hz than the 3G and 4G spectrum. A similar reasoning of cost reduction and performance improvement can be made with regard to small cells as opposed to 4G macrocells (Andrews et al., 2014).

#### 2.1.3.4 Further Focus on Requirements

The concept of 5G requirements to be met in order to have a practical relevance in the real world is further stressed by Rao and Prasad (2018) in their article "Impact of 5G Technologies on Smart City Implementation" in which they underline how 5G should meet:

- *Relaxed latency requirements* in order to enable remote meter reading for billing purposes
- *Strict latency requirements* for enabling all that services that require a rapid and effective response like real time traffic control and real-time patient monitoring
- *High levels of network reliability* for the functioning of electrical grinds and industrial control
- *Relaxed level of network reliability* for permitting the monitoring of temperatures inside the houses
- *High volume of Information and Low volume of information* depending on the different cases of applications like video surveillance or cargo tracking
- *Low device cost/ low energy* for enabling the function of sensors that are battery powered.

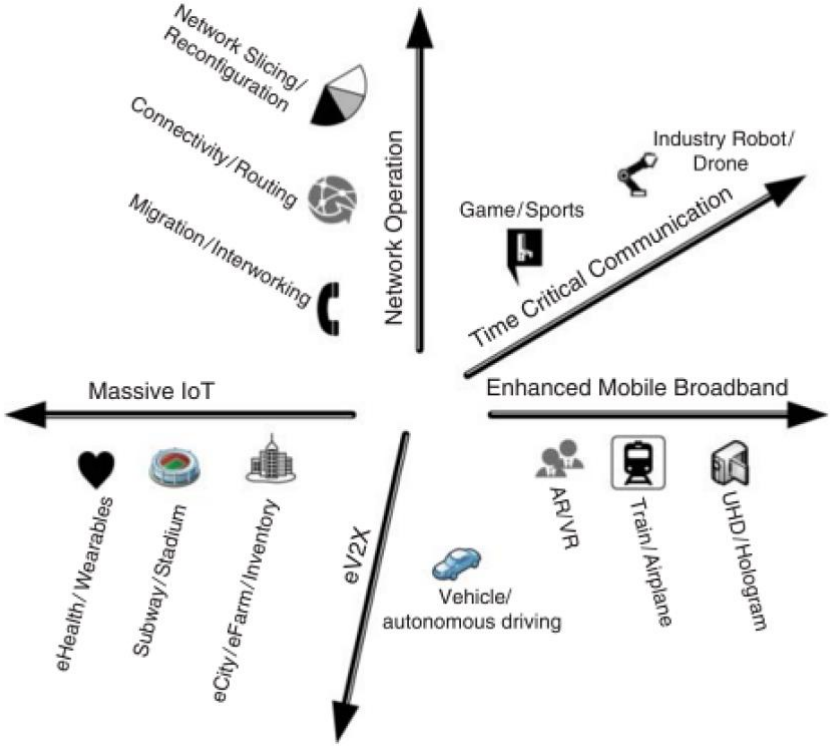
### 2.1.4 5G relationship with the Industrial World

In order to get a clearer idea of where 5G will impact the most we can focus on the industries that will undergo a digital transformation due to changes in the market. There are several cases of industries where 5G can play a crucial role in connecting people and things:

- *Healthcare*: where the most important 5G applications will be bioelectronic medicine, tele medics and augmented/virtual reality.
- *Manufacturing*: with the monitoring of robotic instruments and the application of machine-to-machine communication within factories.
- *Entertainment*: where a more immersive and totalizing consumer experience will be developed.
- *Automotive*: where infotainment, autonomous driving and remote maintenance will be mature in a short time.
- *Energy*: with connected windfarms and grid and control monitoring.
- *Public transport*: where the infotainment and the train/bus operations will leverage on 5G technology.
- *Agriculture*: where the employment of modern farming machines, connecting sensors and drone control will become of crucial impact in the future
- *Public Safety*: with the development of threat detection systems, facial recognition and drones.
- *Megacities and Smart Cities*: the cities of the future will be connected. Thanks to 5G the number of sensors and objects that will be connected will rocket up and we will have the opportunity to monitor the pollution and the energy consumption of our cities. Our towns will be safer, the public transport performance will improve, and the parking system will be bettered (Chandramouli et al., 2019).

### 2.1.5 5G use cases

Figure 3: 5G use case categories – (Chandramouli et al., 2019, p.10)




While the previous chapter gave us an overview of the industrial sectors that could be most affected by the impact of 5G technology, in this chapter we will analyze what are the main applications of this technology through the study of some use cases: in order to have a better understanding of the various applications for this technology we can divide them in some macro areas (Fig.2).

#### 2.1.5.1 Massive IoT

In massive IoT, an increasing number of sensors will be involved in sending signals. Massive IoT lays its roots the so-called Internet of Things (IoT) which is described by Mumtaz et al., (2017, p.28) as the "interconnection of intelligent devices and management platforms that, with little to no human intervention, collectively facilitates a smart, connected word". Rao and Prasad (2018) in their article "Impact of 5G Technologies on Industry 4.0" stress how Internet of things and 5G technology share a profound bond laying in the fact that 5G can be considered to be one of the enablers of IoT thanks to the reliability, latency, scalability, and edgeless computing that are required for several critical IoT applications. One application of 5G technology within the IoT industry will be the control of industrial robots, which need high reliability and low latency. Another application are the wearable devices that require nomadic connectivity and to cover very large areas through so-called global roaming. Massive IoT applications will require security and privacy in every different context and 5G will be able to provide them (Chandramouli et al., 2019).

#### 2.1.5.2 Time Critical Communication

Another interesting macro-area in which 5G could play an important role is the one of Time Critical Communication: some use cases regarding this area are the utilization of drones in order to perform routine maintenance on equipment and the elimination of wires in robotic factories (Chandramouli et al., 2019). This kind of use cases flow into the implementation of industry 4.0, which is defined by Lu (2017, p.2) as "the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes". The author also suggests that industry 4.0 will be an advocate of the evolution of industry as we know it today towards the adoption of information driven and interconnected systems. Among the objectives of industry 4.0 are the evolution of the production chain towards flexibility and adaptability in real time, the ability to track products once they have left the factory and the constant real-time communication between components, products and machines (Lu, 2017). For such an evolution to be possible, it is necessary that 5G can support time critical communication and reliable processing in factories. A basic requirement for industry 4.0 and smart factory is the presence of efficient production lines and real-time monitoring of the quality of finished products. To make this possible, it would be necessary that the sensors used in the factories of the future are efficient and can rely on the ability to collect data in real time through ultra-low latency. At the same time, robots that perform the function of product assembly need to adopt time critical communication in order to be as effective as possible. Rao and Prasad (2018) in their article "Impact of 5G Technologies on Industry 4.0" stress how 5G is the answer to these requirements and can undoubtedly be considered a facilitator for all those industrial applications that require real-time data communication for an immediate response.

#### 2.1.5.3 Mobile Connectivity

When we talk about 5G we always consider ingenious and futuristic applications, such as massive IoT, or industry 4.0, or autonomous driving. But we must not forget that the introduction of the 5G network will have its most immediate effects on mobile connectivity. Thanks to 5G the actual mobile broadband will be bettered and upgraded. The customer will witness better coverage in rural areas, which nowadays are not covered by mobile signal or can't go beyond the edge rate mobile coverage. Connectivity will be improved in motion conditions, such as during a flight or train trip (Chandramouli et al., 2019).

Table 1: Comparison of a classical 5G urban scenario with a rural one – (Chiaraviglio et al., 2017, p.51)

| | 5G urban scenario | 5G rural scenario |
|---|---|---|
| Service type | HD video, HD streaming, tactile Internet, IoT | HD video, emergency service, e-Health, e-Learning |
| Network constraints | Maximize bandwidth, minimize delay, coverage | Coverage, guaranteed bandwidth |
| Energy sources | Power grid | Power grid, renewable sources |
| Monthly user subscription fee | Pay per bandwidth | Same as standard urban users |
| Business model | Return on investment | Subsidized by the government |
| Required network flexibility | High | High |
| User mobility | Pedestrian, vehicular, high-speed vehicular | Pedestrian, vehicular |

Today, at least two billion people are experiencing the absence of wireless cellular network coverage. These people who would like to use the services of the network to connect to the world live in rural areas and earn very little money. In these areas the operators are not willing to invest because they do not consider them profitable for their business (Chiaraviglio et al., 2017). Table 1 shows the difference between an urban scenario and a rural scenario for 5G. In particular the type of service and the network constraints differ significantly. Rural areas do not need high speed and ultra-low latency, but they need to be connected to the rest of the world, in order to reduce the digital divide.

#### 2.1.5.4 Vehicular Communication Sector

One of the macro-areas in which 5G finds its main applications is the vehicular communication sector. Vlachos et al., (2017, p.1) state that "Automotive industry will be greatly benefited by the advent of 5G Networking and the huge boost in performance and coverage it will support". In particular in this field 5G can be used for vehicle automation and for the V2X (vehicle to everything) communication. Vehicle-to-everything (V2X) incorporates vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), Vehicle-to-infrastructure (V2I), and vehicle to network (V2N) communications, and it will have a great impact in the improvement of road

safety, traffic efficiency and the various infotainment services that nowadays are fundamental aspects regarding the evolution of the automotive industry (Chen et al., 2017).

Chandramouli et al., (2019) identify different levels of automation (0-5) that determine the different use cases in which 5G can impact V2X communications.

- Level 0 (no. automation): Automated systems could intervene is case of signaling warnings for the vehicles, but the driver still controls the vehicle.
- Level 1 (drive assistance): The driver is no longer the only one in charge for the control of the vehicle, but the automated system is in part in charge of it. An example of this system is the ACC (Adaptive Cruise Control), in which the driver is still in charge for the steering wheel, but the automated system controls the speed and the parking. In this scenario the driver can always retake the command of the vehicle.
- Level 2 (partial automation): In this use case, the system is now responsible for a lot of tasks that usually are carried by the driver like acceleration, braking and steering. But the driver still has to be ready to intervene at any time.
- Level 3 (conditional automation): The driver is no longer responsible for the main tasks. The vehicle system will be responsible for all that moments that require prompt intervention like braking in dangerous situations.
- Level 4 (high automation): The driver is not in charge of anything, and any job is carried by the vehicle. In the high automation level, the driver could even fall asleep during the trip and the car will still arrive at the destination designed, but the driver could still retake the control of the car if it is needed or in particular situations.
- Level 5 (full automation): In this level there is no need for human intervention anymore. The system of the car, which is enabled by the 5G technology carries all the necessary tasks.

#### 2.1.5.5 Network Operations

The last macro area of influence that is going to be discussed in this section is the one of network operations: One of the major applications of 5G within the network operation sector is the possibility to offer communication services minimizing the resources that are used within a network. 5G can also provide the power needed to use the network itself and the power consumption needed to use different types of devices (Chandramouli et al., 2019). Zhang et al., (2017, p.138) state how: "5G systems are expected to provide society with full connection, which can break through the limitations of time and space to create all-dimensional user-centred or service-centric interconnections between people and things".

The authors also explain how that 5G networks have the goal to meet different requirements in various scenarios in order to meet particular user quality of service (Qos) requirements. In scenarios where there is the need of wide-area coverage, network slicing enabled by 5G networks should provide a high data rate service in any period and everywhere. In areas located in cities where there is the demand for a high volume of data

traffic, 5G networks should guarantee hotspot coverage and capacity. In scenarios where there is the need for connections for low-power sensors, 5G networks should guarantee the connections of millions of devices with a low impact on cost and power consumption for every device that should be utilized. Thanks to the phenomenon of network slicing, which consists in the division of a physical network in different logical networks, it will be possible to deliver had hoc services for various applications scenarios utilizing the same physical network (Zhang et al., 2017).

## 2.2 Towards the Concept of Business Ecosystem

The notion of ecosystem comes from the biological sciences. Biological ecosystems are composed of a number of species that have interdependent links with each other. In the same way, in a business ecosystem it is the various organizations that are interdependent in nature. Just as the future and proliferation of a biological ecosystem depends on the relationship between the various species, in the same way the future and proliferation of a business ecosystem depends on the interdependencies of the organizations that constitute the ecosystem itself (Iansiti & Levien, 2004). In a business ecosystem, companies form different industries cooperate and compete to develop products and services in order to satisfy the customer needs. In doing so they build new skills and capabilities around the new innovations that they want to bring to the market. For example, Apple Computer has established itself as the leader of an ecosystem that builds its strength around four different industries: personal computers, consumer electronics, information and communications (Moore, 1993).

### 2.2.1 Business Stages of Evolution

A business ecosystem, like its biological counterpart, has different stages of evolution: birth, expansion, leadership, self-renewal or death. Executives need to be aware of the various changes a business ecosystem is facing, and they have to be prepared to detect the possible changes that could occur (Moore, 1993).

During the stage of birth, the value proposition of a new product or service to be delivered to the customer is defined. In this stage the entrepreneurs that manage to define and implement correctly the value proposition are the ones that win in the short term and take the position of leaders in the ecosystem. Leaders often seek for other companies (partners) in order to successfully deliver the full package of value to the customer. While seeking and acquiring for partners they could exclude the most important ones from helping other emerging ecosystems in order to gain competitive advantage (Moore, 1993).

In the stage of expansion business ecosystems expand for the conquest of new territories. In order to achieve expansion, there are two requirements that must be fulfilled: a business concept that can be appreciated by a large number of consumers and the potential to scale up the concept in order to reach a wider market. In

general, this phase is characterized by the fact that some ecosystems manage to establish themselves at the expense of others and drive them out of the market. To do this, companies must maintain control of consumer relations and centers of innovation and value. They must also develop relationships with their suppliers, in order to prevent other ecosystems from excelling (Moore, 1993).

In the leadership stage, companies within a business ecosystem clash one another in order to determine which is the leading one. There are two conditions that determine whether or not it makes sense to fight for the leadership of an ecosystem. First of all, the ecosystem must have broad growth prospects and a fairly large profit margin. Second, the structure of the components that contribute to add value and the central processes of the business ecosystem must be stable. In this stage companies become more concerned with standards, modularity within the ecosystem and customer-supplier relationship. To establish their leadership within an ecosystem, companies can leverage the fact that they are the only ones who have a fundamental resource in order to deliver the value proposition to the customer. At the same time, dominating companies work to strengthen their key roles through contributions to improve ecosystem performance and try to establish their core roles through contributions to improve the overall ecosystem (Moore, 1993).

In the last stage, the stage or renewal or death, the most important task is to confront obsolescence. For an ecosystem to be successful in the long term, it must be able to renew itself and take on successive generations of innovations. The dominant companies within an ecosystem can participate in this phase in three different ways. They can try to slow the growth of new ecosystems, they can try to incorporate new innovations into their ecosystem, or they can try to modify their structure in order to face the reality around them (Moore, 1993).

### 2.2.2 Definition of Business Ecosystem

The definition of ecosystem has different facets. Many authors have contributed to define what a business ecosystem is and therefore, in order to have a clear and understandable definition of business ecosystem it is necessary to consider more scholars. According to Adner (2017, p.40) an ecosystem can be defined as: “the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize”. While describing an ecosystem, a fundamental distinction between two different ways of seeing an ecosystem needs to be done. If we define an ecosystem as an affiliation, we describe an ecosystem depending on the networks and the platforms that link all the participants. If we describe an ecosystem as a structure we focus on the activities, within a certain ecosystem, that are carried out in order to deliver a certain value proposition (Adner, 2017). According to Kapoor (2018, p.2) “an ecosystem encompasses a set of actors that contribute to the focal offer’s user value proposition”. This definition takes into account the link between the demand side and the supply side of a focal offer and places greater interest in the actors of the multiple

industries that contribute to the value creation of the focal offer (Kapoor, 2018). Hannah and Eisenhardt (2018, p.1) define ecosystems as "collections of firms that produce discrete products or services that together comprise a coherent solution", underlining also here the contribution of different companies to the realization of a product and service. Even if the focus on the value proposition is not directly mentioned, the definition seems to be in line with the previous ones.

### 2.2.3 Elements of a Business Ecosystem

Once a definition of business ecosystem has been identified in a set of firms from different industries that collaborate in the creation of a value proposition for the end customer, it is necessary to understand what are the elements that characterize an ecosystem. The elements that characterize an ecosystem are: the *activities* that must be carried out to deliver the value proposition, the *actors* that are the entities that must carry out the above mentioned activities, the *positions* that identify where the actors are located and in the *links* that specify transfers from one actor to another and the characteristics of these transfers (Adner, 2017).

An ecosystem is characterized by the *activities* that serve to realize the different value offers of the *actors*, i.e. the participating companies within the ecosystem. The various value offers, the individual actors and the offers that contribute to the creation of a business ecosystem are connected to each other through *technologies and production architectures*. Architectures are based on technological interactions among offers and in relations concerning input-output flows between the actors of the ecosystem (Kapoor, 2018). In order to outline a homogeneous composition of the entities that make up the ecosystem, it is possible to summarize them into three categories: *Actors, Activities* and *Platforms*. In particular the concept of *Platform* is utilized to describe the nature (technological or not) of the linkages among actors and offers, but not the bargaining or the nature of the relations that can be witnessed among the various actors of the ecosystem, which is object of the ecosystem strategy (Adner 2017, Kapoor 2018).

#### 2.2.3.1 Actors

Among the various actors that constitute a business ecosystem is possible to identify the *focal firm* and the *complementors*.

#### 2.2.3.2 Focal Firm

The focal firm exercises the role of leader within the ecosystem and plays a central function in terms of contribution. Without the contribution of the focal firm the other members of the ecosystem find it extremely difficult to achieve their professional goals (Moore, 1993). Thanks to its predominant role a focal firm can determine which is the vision and which are the common goals that all the participants of an ecosystem should

follow (Moore, 1996). Usually the leading firm has the power to influence the other participants of the ecosystem in following its philosophy and standards (Baghbadorani & Harandi., 2012).

#### 2.2.3.3 Complementors

The actors involved in a business ecosystem can be of different nature and can have different levels of contribution towards the common value proposition of the ecosystem. When studying a business ecosystem, the focus is usually pointed towards the so called *complementors*. Complementors are considered those actors who "produce complementary products and services that contribute towards the focal offer's value creation" (Kapoor, 2018, p.7). The more important the contribution in terms of a single offer of a complementor is, the more the complementor is considered as significant in the ecosystem balance. When dealing with complementors it is necessary to create an alignment structure, which can facilitate the realization of joint value and limit the conflicts that may arise when one or more complementors may have a battle regarding the capture of the value produced within the ecosystem (Kapoor, 2018).

#### 2.2.3.4 Activities

Among the activities is possible to distinguish three different main concepts: the concept of *component*, the concept of *bottleneck* (with its different types) and the concept of *platform*.

#### 2.2.3.5 Components

Activities are all the actions that produce offers that contribute to deliver the final value proposition of a business ecosystem. The contributions can be in terms of products and/or services and take the name of *components*. For example, Apple was able to create an ecosystem based on a conglomerate of firms that provided different components such as MP3 player, flash memory, digital music rights and the iTunes store, which contributed to the creation of the final value proposition of the iPod (Hannah & Eisenhardt, 2018). The nature of a business component can be varied and include different value offers that contribute to the success of the final product or service. In fact, it can include business objects, business resources, business activities, business services, but also contributions related to the regulations that are necessary to operate in a given sector. When we want to study the relationships between the different members of a business ecosystem, the role of the activities carried out by companies is replaced by that of components (Zhang & Fan, 2010).

#### 2.2.3.6 Bottlenecks

A bottleneck is a component of a business ecosystem whose performance hinders or impedes the functioning of the entire ecosystem. The criticality of a bottleneck lies in the fact that it leads to performance constraints and there is no alternative at the present time that can replace it (Baldwin, 2015). In particular, some of the contributions in terms of offer towards the final value proposition, i.e. some components of the ecosystem,

may represent limitations in terms of performance, costs or scarcity and therefore limit the performance of the entire ecosystem (Kapoor, 2018). Bottlenecks slow down the growth of the ecosystem due to their poor quality and limited efficiency. For example, buying digital music on iTunes was a serious bottleneck in the iPod ecosystem, and only when it was fully resolved the iPod could lead the market (Hannah & Eisenhardt, 2018). Bottlenecks must be distinguished from networks structural holes. If a network has a structural hole it can still perform its function and an actor in a network that occupies a structural hole can do arbitrage operations between the other actors who would otherwise be disconnected without it. On the contrary a bottleneck damages the entire ecosystem and if it is not solved it does not allow the ecosystem to perform properly. If an ecosystem complementor can solve a given bottleneck, it must be able to capture the value that comes from it, but if it wants the ecosystem to work, it cannot benefit totally from brokerage operations with other actors in the ecosystem (Hannah & Eisenhardt, 2018).

Moore (1993, p.81) states that "Bargaining power comes from having something the ecosystem needs and being the only practical source", but this bargain is limited by the proper functioning of the business ecosystem. A firm that is able to solve a bottleneck must be able to capture the most of the value from it, but for an ecosystem to work (which would also make a huge contribution to the firm that solved the bottleneck), the information for solving the bottleneck must be shared.

#### 2.2.3.6.1 Types of Bottlenecks

Bottlenecks can be of two types: technical and strategic. Technical bottlenecks occur when the obstacle to an ecosystem performance derives from the physical characteristics of the ecosystem itself. For example, in a railway, if there is no bridge connecting the two banks of a river, a technical bottleneck is encountered. Bottlenecks of a strategic nature occur when the solution to a technical bottleneck exists, but it is not possible to benefit from it, so payment is needed in order to use it. There are three subcategories of technical bottlenecks: sine qua non bottlenecks, flow bottlenecks and matching bottlenecks. Sine qua non bottlenecks concern components necessary for the basic functioning of the ecosystem, if there are such bottlenecks the ecosystem cannot exist. Flow bottlenecks concern low capacity problems of components. Matching bottlenecks regard components that do not match properly in ecosystems that require parts to fit together in order to function properly (Baldwin, 2015).

### 2.2.3.7 Platforms

The study of platforms concerns the technology and production architectures that allow the fundamental connection between the offers and the actors of the ecosystem. Platform based ecosystems are managed by the owner of the platform. The owner of the platform, managing the alignment structure, enables complementors to participate in the ecosystem following certain rules and procedures. Product based ecosystems provide for market level interactions between the platform firm (which in this case plays the role of the focal company), the complementors and the end users. In this case the alignment structure between the different complementors

is determined by all the participants in the business ecosystem (Kapoor, 2018). The architecture of an ecosystem makes it possible to describe the relationships between the components of an ecosystem and to study the way they interact with each other. In studying the architecture of an ecosystem, it is necessary to take into account both technical architecture and industrial architecture. Technical architecture relates to the technical tasks necessary to produce a product or service according to its material structure. Industry architecture is defined as the aggregate of various contract structures. Contract structures include practices, constraints, contracts, property rights and transactions existing within the ecosystem (Baldwin, 2015).

### 2.2.4 Ecosystem Strategy

The study of the different relationships and balances of power within a business ecosystem is the object of the ecosystem strategy. Adner (2017, p.47) defines the ecosystem strategy as: "the way in which a focal firm approaches the alignment of partners and secures its role in a competitive ecosystem". The purpose of ecosystem strategy is to study the relationships between the various actors that are part of the ecosystem and contribute to the final value proposition (Kapoor, 2018). This vision can be extended by taking into account the fact that the ecosystem strategy is defined as the choice of a company with regard to its components, its complementarities and the *balance between cooperation and competition* (Hannah & Eisenhardt, 2018). The study of cooperation and competition within a business ecosystem is fundamental for understanding the dynamics that govern it. In fact, the companies that make up an ecosystem work competitively and cooperatively to develop new products and meet consumer needs. The balance of competition and cooperation strategies results in the coevolution of the ecosystem (Moore, 1993). The evolution of an ecosystem is the fundamental element that keeps the ecosystem alive and cooperation and competition are the phenomena that regulate it. Competition and cooperation within an ecosystem can be studied by taking into account the relationships between the various partners (*alignment of partners*) and by studying ecosystem strategies related to the *management of bottlenecks*, which are the most important resources for a business ecosystem.

#### 2.2.4.1 Alignment of Partners

One of the ways in which to study business ecosystems is to focus on how partners manage relationships with each other and with the focal firm. Specifically, the alignment of partners focuses on the focal firm's ability to align various complementors with the positions and roles that the business ecosystem vision conceives. Gaps may emerge between the various complementors or between the focal firm and the individual complementors, and the focal firm must be able to close them for the ecosystem to work (Adner, 2017). In order to study the relationships between the various partners of an ecosystem it is necessary to consider the concepts of *complementarity* and *interdependency*. To critically analyze the damage that an incorrect alignment of partners can cause, it is necessary to investigate *co-innovation risks* and *integration risks* through the mapping of an ecosystem, in fact : “A meaningful ecosystem strategy will be explicit in assessing, and proactive in managing, these risks” (Adner, 2017 p.48).

#### 2.2.4.2 Complementarities

The concept of complementarity in a business ecosystem stems from the need of the various components to be organized around a final product or service. In fact, in order for the final value proposition to be realized it is necessary that all the components are present (Hannah & Eisenhardt, 2018). The components of a business ecosystem create value only thanks to their complementarity. In fact, the value generated by the set of components taken in their complementarity is much higher than that of the components taken individually (Baldwin, 2015). The degree of complementarity varies according to how a component relates to the overall value offer of the ecosystem. We find ourselves in a case of close complementarity when the focal offer and the single component have no standalone value. Their value is real only when they are used together such as a mobile phone and a mobile operating system. We find ourselves in a case of super modular complementarity when the more a component is present, the greater the contribution towards the value offer is. An example are smartphone applications or charging stations for an electric car. Another feature regarding complementarity is that it can be generic or specialized with respect to the focal offer (Kapoor, 2018). According to Kapoor (2018, p.3) complementarities are "economic relationships between offers in terms of the potential of value creation".

#### 2.2.4.3 Interdependencies

The interdependencies between the various actors of an ecosystem arise from the fact that the offers they propose are connected at the level of architecture by the ecosystem itself. Interdependencies consist of structural relationships that help to explain how the change of one offer by one complementor can have an effect on the contributions from the offers of the other complementors. Interdependence is characterized by the fact that it focuses on the demand side of focal offer and the end user has a say in the integration of the various components provided by the complementors to ensure the focal offer (Kapoor, 2018).

Hannah and Eisenhardt (2018, p.2) state that "The interdependence between complementary components can be complex, with underlying activity flows that govern how components interface". Interdependence is different from the complementarity: we could define interdependence as the study of how you manage complementarity.

### 2.2.4.4 Co-Innovation Risks

When studying the relationships between the various partners within a business ecosystem, risks may emerge regarding the way these relationships are conducted. These risks include co-innovation risks. They refer to any difficulties that the complementors may face in carrying out new activities related to the contribution for the development of the value proposition (Adner, 2017). These risks are also called *interdependence risks* and refer to the possible delays that may occur when one or more complementors that should collaborate in the innovation process for delivering the final value proposition do not achieve successful development of their components at the required time. The more a value proposition depends on the simultaneous development of other components the more the interdependence risk is high (Adner, 2006).

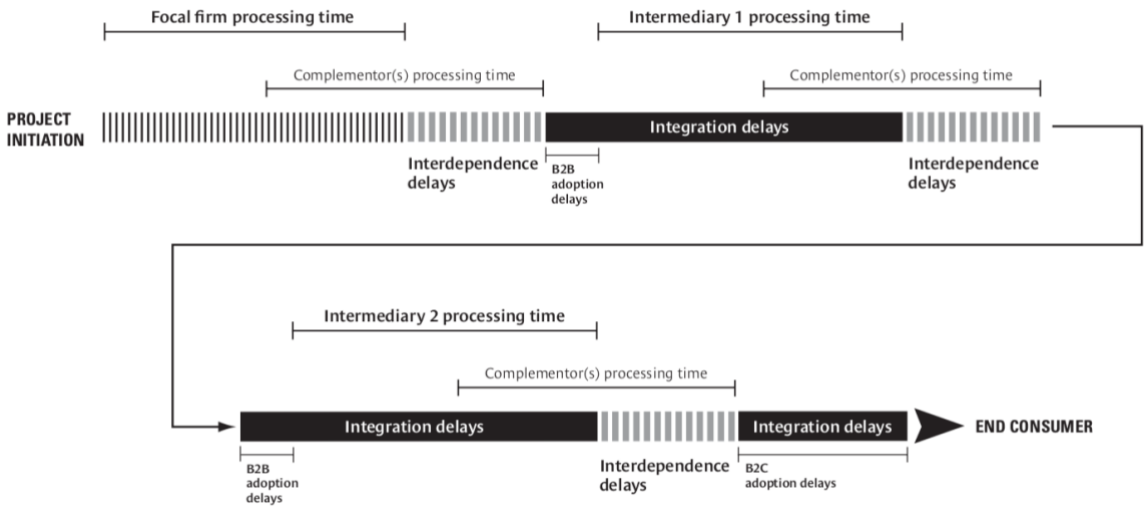
### 2.2.4.5 Adoption Chain Risks

Another risk concerning the alignment of partners in an ecosystem concerns the so-called adoption chain risk. This type of risk concerns the willingness or not of ecosystem complementors to take part in the activities required to deliver to the market the final value proposition and raises questions about incentives to participate in a business ecosystem (Adner, 2017). These risks are also called *integration risks* and refer to all intermediaries along the value chain who must adopt a certain value proposition for allowing that value proposition to achieve a satisfactory number of sales in the market (Adner, 2006).

### 2.2.4.6 Mapping the Ecosystem

After having established what are the characteristics to take into account when we want to study the relationships between the different actors participating in an ecosystem, we can introduce a tool that can help us to analyze them: The ecosystem mapping.

Figure 4: Mapping the Ecosystem – (Adner, 2006, p.7)



Mapping the ecosystem is a process that consists of several stages. First of all, it is necessary to identify all the intermediaries who must adopt an innovation before it reaches the final consumer. Subsequently the identification of all the components (the other value offers that must be made by the complementors in order to realize the final value offer) is done. After these first two phases there is the estimation of all the delays caused by the interdependence with the complementors, i.e. the estimation of what are the *interdependence risks*. The next step involves estimating the delays caused by the time needed for each intermediary along the value chain to adopt the value offer so that it reaches the market, this step coincides with the estimation of what are the *integration risks*. The analysis carried out up to this point focuses on the perspective of a focal value offer (coming from a specific focal firm) and the relationships of the focal firm with its complementors and intermediaries. The ecosystem mapping is a complete tool of analysis, in fact it is necessary to estimate also the delays caused by the interdependence of the intermediaries with their respective complementors (*intermediaries' interdependence risk*) and the delays caused within the value chain of the single intermediaries (*intermediaries' integration risks*). Once, thanks to the ecosystem mapping, all the problems within a business ecosystem have been identified, is possible to define if the expectations regarding the arrival of the value offer on the market are confirmed or denied. In the second case is possible to adopt strategic solutions, modify relationships with partners or act at market level to close the gap between the estimated time for delivery of a given value offer on the market and the actual time due to the estimation of different delays (Adner, 2006).

### 2.2.5 Bottleneck Strategy

The mapping of a business ecosystem provides relevant information on the relationships between the various players in relation to their contribution in terms of value offer to the final value proposition. However, this study approach does not take into account one of the fundamental elements of ecosystem composition, bottlenecks. The characteristics of bottlenecks have already been discussed in the dedicated paragraphs, so this paragraph will explain how through the bottleneck strategy it is possible to study the way a business ecosystem behaves in front of the presence of bottlenecks. According to Hannah and Eisenhardt (2018) bottleneck strategy consists of several stages. The first phase consists of unlocking components that are bottlenecks due to their performance or shortage problems. The second step is to innovate these components/bottlenecks and the third step is to work with complementors to assemble the remaining components of the ecosystem. This strategy foresees a reciprocal relationship between cooperation and competition between the partners of an ecosystem: when a business ecosystem actor succeeds in unlocking a bottleneck, he must be able to create value (cooperate to assemble the entire ecosystem) and capture value (compete by exercising market power). In order to decide to what extent, cooperate and to what extent compete with the surrounding ecosystem while successfully addressing bottlenecks, it is necessary to consider the concept of *bottleneck crowdedness*. A bottleneck is considered crowded when the value offer of which it is composed is provided by a large number of complementors. Conversely, a bottleneck is considered

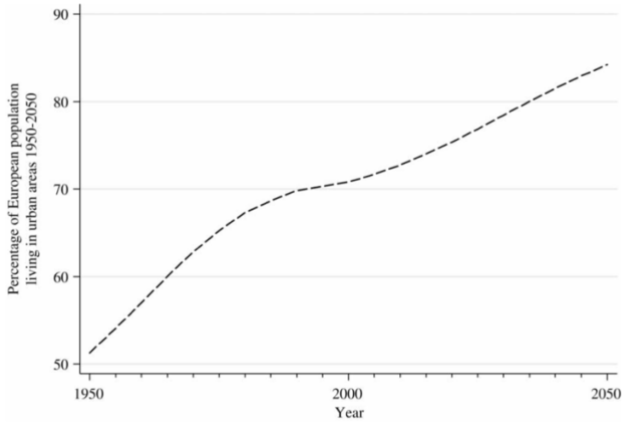
uncrowded when the value offer (component) of which it is composed is provided by a small number of complementors. If a bottleneck turns out to be crowded, it is necessary to collaborate, whereas if a bottleneck turns out to be uncrowded, it is necessary to compete.

Companies that want to create value through technology have the necessary need to search and solve bottlenecks. Once they have been solved it is necessary to control them. In order to understand if a given component is a bottleneck, who decides to try to identify them has to compare them to a broader system. It is necessary to understand what constitutes good performance at the system level and how bottlenecks impact negatively on that kind of performance. Technical bottlenecks can be located within a system and it is also possible to map the specific components that contribute to the creation of the bottleneck. In particular, intensive bottlenecks are caused by lack of performance in one of the components, while extensive bottlenecks are caused by lack of performance of several components. Technical bottlenecks are identified when a particular component of an ecosystem is studied, and it is observed how it contributes to the performance of the entire system. If the system fails to perform in the desired way because of such a component, a bottleneck is faced (Baldwin, 2015).

## 2.3 Introduction to Smart Cities

Cities play a key role in social and economic aspects and have a strong environmental impact. According to the United Population Fund in 2008 more than 50% of people lived in urban agglomerations and this percentage is expected to rise to 70% by 2050 (Albino et al., 2015).

Figure 5: Smart Cities in Europe – (Caragliu et al., 2011, p.66)




Evidence of this disproportionate increase in the size of cities can be seen in what are considered megacities. That is, cities with more than 20 million inhabitants. Cities are growing and consuming more and more: in 2008 cities consumed between 60% and 80% of the global energy and were the main responsible for green

gas emissions. At the same time as the increase in emissions there has been a decrease in terms of quality of services and infrastructures due to the constant increase in population (Albino, 2015). Joshi et al., (2016, p.903) state that "Problems related to health, traffic, pollution, scarcity of resources, waste management and poor infrastructure arise and hence development of city falls apart". To cope with this, cities began to look for solutions to improve the environmental impact and to improve urban services in cities in the long term. Most of the approaches for improving urban services have been based on the use of technology and in particular ICTs (Information and Communication Technologies) to create what today are called smart cities (Albino et al., 2015).

### 2.3.1 Definition of a Smart City

Smart cities can be defined in a number of ways and many authors have contributed to the most comprehensive definition of what a smart city is. Washburn et al., (2009) emphasize that within a smart city the use of smart computing technologies is of fundamental importance to realize infrastructure and services (healthcare, real estate, public transport and city administration) interconnected and efficient. The authors stressed that the computerization of these services is of great importance to improve the current condition of cities, which often have to live with inadequate infrastructure and poor services for the citizen. Giffinger et al., (2007) stress that smart cities can have a significant impact on the economy, people, mobility and environment to which European citizens relate today. Hall (2000) defines smart cities as a place where all major infrastructures such as roads, tunnels, railways, airports, buildings and subways are monitored in order to plan more efficiently the use of resources and maintenance activities. The monitoring of infrastructures ensures greater safety for citizens by providing them with the best possible services (Hall, 2000). Harrison et al., (2010) define the smart city as an instrumented, interconnected and intelligent city. The instrumentation allows to capture and integrate collected data through the use of sensors, meters, personal devices, cameras, smartphones and any other system that allows the acquisition of data such as the web, which allows to keep track of people's habits and interests. The interconnection allows these data to be processed through computing platform systems and then to be communicated to the entities that need them for the operation of all the smart services available in the city. The adjective intelligent refers to the use of complex models to process data and make better decisions. However, there are other definitions that take into account other aspects of fundamental importance. Rios (2012) defines a smart city as a city that inspires, shares culture and knowledge and encourages its inhabitants to improve important aspects of their lives. Partridge (2004) defines the smart city as a city where ICTs can play a fundamental role in order to implement information and services that are provided to the public.

### 2.3.2 Smart City as Ecosystem

Although the definition of the concept of smart city is still vague, it is possible to identify the smart city as an ecosystem devoted to innovation, entrepreneurship and creativity that bases its implementation on an

information technology network (Anttiroiko et al., 2014). The concept of the city as a smart ecosystem, which provides a large amount of advanced services built around the characteristics of the end user, comes from the extension of the concept of smart space, which can be defined as a space that improves the life of citizens in a given context thanks to the ability to acquire and critically analyze data regarding the context and the citizens themselves (Yovanof & Hazapis, 2009).

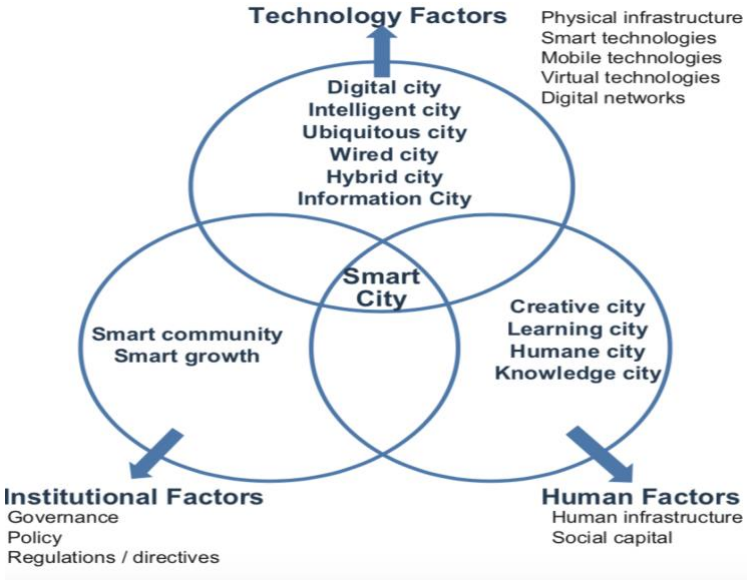
Starting from the concept of smart space and considering how cities are becoming interconnected ecosystems dependent on digital components coordinated with each other, we come to the definition of smart city as an ecosystem. This is underlined by the fact that our conception of cities is changing considerably from static to dynamic. Urban conurbations that were seen as a collection of buildings and immobile infrastructure are changing into smart ecosystems that are often referred to as intelligent cities (Yovanof & Hazapis, 2009). An intelligent city is an area in which innovation systems and ICTs are combined together and connected with creative individuals, institutions that leverage learning and innovation, digital spaces that enhance the supervision of knowledge and sustain innovation (Komninos, 2006). A smart city can be defined as an ecosystem in which we see the presence of different technologies connected to each other in such a way as to guarantee an improvement in the functions performed in a city. In particular, these technologies have the task of collecting, sharing and analyzing data in real time. An ecosystem of this type requires the presence of different stakeholders who must collaborate with each other (Abu-Matar, 2016). Couzineau-Zegwaard et al., (2013) highlighted in their study that it is possible to compare the concept of smart city with that of business ecosystem. In their paper the authors first of all listed the characteristics of a business ecosystem (such as the keystone company or focal firm, the number of actors within the ecosystem, the network and the platform). Then they illustrated a Smart City ecosystem starting from the fact that a smart city "cannot be viewed as a sum of parts but holistically as a network of interconnected infrastructures dependent on each other" (Morvaj et al., 2011, p.2). In order to do this, they considered PlanIT valley, a project for the realization of a smart city in Portugal. In this case the keystone company (or focal firm) consisted of LivingPlanIT, a high technology startup company that had set up the PlanIT Valley project. A real business ecosystem was created around the focal firm. Among the actors involved were companies like Microsoft, Cisco and Philips. The ecosystem also had its own platform called UOS™ (Urban Operating System) which allowed Machine to Machine (M2M) communication between the billions of smart sensors involved in the project. Thanks to the platform, the M2M communication enables healthcare, energy management, transportation and many other components of the ecosystem (Couzineau-Zegwaard et al., 2013).

### 2.3.3 Smart Cities Factors

In order to take into account more broadly what successfully makes a smart city we must take into account the so-called smart city factors. These factors are technological, human and institutional. Technological factors

are among the most important to take into account when approaching a smart city, because through the use of ICTs it is possible to transform the working and social dynamics of a city (Nam & Pardo, 2011). Thanks to the leverage of ICTs is possible to apply "a wide range of electronic and digital technologies to create a cyber, digital, wired, informational or knowledge-based city" (Albino et al., 2015, p.10). Among the human factors we can include creativity, social consciousness and education. In particular it is necessary that the citizens of a smart city are predisposed to IT education and creativity (Nam & Pardo, 2011). One of the objectives of smart cities is to create more cultured, involved and acquainted citizens who can actively participate in the life and governance of the city (Chourabi et al., 2012). Institutional factors include all those actions that the government takes to implement a smart city. In fact, the creation of a smart city involves collaboration between technological components and institutional components in order to make the technological solutions dedicated to the creation of a smart city effective (Nam & Pardo, 2011).

Figure 6: Smart City Factors – (Nam & Pardo, 2011, p.286)




### 2.3.4 Components of a Smart City Ecosystem

After talking about what are the factors that make a smart city, you need to talk about what are the components of a smart city. Giffinger et al., (2007) consider what are the characteristics of a smart city: they are smart economy, smart people, smart governance, smart mobility, smart environment and smart living. Albino et al., (2015) have contributed to expand the concept by linking the above-mentioned components with the respective aspects of urban life as indicated in the table below.

Table 2: Components of a Smart City – (Albino et al., 2015, p.11)

| Components of a smart city | Related aspect of urban life |
|---|---|
| smart economy | Industry |
| smart people | education |
| smart governance | e-democracy |
| smart mobility | logistics & infrastructures |
| smart environment | efficiency & sustainability |
| smart living | security & quality |

The characteristics of Smart City components are further justified by Rao & Prasad (2018) in the article "Impact of 5G Technologies on Smart City Implementation", in which they illustrate some of the components that make up a Smart City. Among them we have for example smart transportation, smart healthcare, smart energy and smart buildings.

#### 2.3.4.1 Smart Transportation

Thanks to the concept of modern connectivity all means of transport are interconnected and mobility has completely changed its face. Integrating smart transportation systems within the city would improve public transport service, reduce costs and increase security (Silva et al., 2018). When talking about Smart Transportation we have to consider some subcategories that describe in detail what will be developed in cities in order to have an intelligent transport system: smart public transportation system, smart traffic information system, smart parking management system, intelligent traffic management and control system, safety management and emergency systems and smart pavement management system (Agarwal et al., 2015).

#### 2.3.4.2 Smart Mobility

The smart mobility concept dates back to the 1990s and highlights how mobility within a city is dependent on technology and innovation. In particular, the technocentric approach highlights how the ICT infrastructure is one of the pillars on which smart mobility rests and how smart mobility approaches smart cities (Papa & Lauwers, 2015). One of the main applications of smart mobility are autonomous vehicles. An autonomous vehicle, thanks to the use of technologies that implement its connectivity and sensors that capture data, increases road safety, improves traffic flow and reduces energy consumption. The leverage of technological solutions in a vehicle, not only improves performance in terms of safety and environmental impact, but also betters the information service for the driver and provides a quality improvement in the entertainment service for passengers (Olaverri-Monreal, 2016). Within the smart mobility domain, one of the concepts that has become predominant is Mobility as Service or Maas (Pangbourne et al., 2018). The service offered by Maas implies the utilization of a single application to use, through an online payment of a time-dependent tariff, a specific means of transport within the city (Li & Voege, 2017). Another facet of smart mobility is the car

sharing system, which aims to reduce the costs and environmental impact of private transport by replacing the proprietary system with an access-based consumption system (Bardhi & Eckhardt, 2012).

#### 2.3.4.3 Smart Healthcare

Smart healthcare can be defined as: "the provision of health services by using the context-aware network and sensing infrastructure of smart cities" (Solanas et al., 2014, p. 76). The increase in the world's population is creating numerous healthcare problems. The number of doctors is not growing in proportion to the increase in population. The aim of smart healthcare is to improve the service offered to patients and at the same time to close the gap between supply and demand (Silva et al., 2018). One of the most important applications of smart healthcare is remote health monitoring, which can be used to visit non-critical patients remotely, thus reducing the number of doctors in the hospital (Baker et al., 2017). Smart healthcare can be defined as the combination of traditional medical practices and those that leverage sensors, wearable devices, emergency services, ICTs, could computing, fog computing, smart phone applications and data processing. In order to realize the concept of smart city it is of fundamental importance to integrate smart healthcare systems into it (Silva et al., 2018).

#### 2.3.4.4 Smart Energy

Smart energy will leverage on renewable energy sources like solar power and wind power. The problem with this kind or energy sources is that they lack the flexibility guaranteed by the fossil fuels. In order to reduce this gap between renewable and non-renewable energy sources, it is necessary to use certain technologies, which will be the foundation of the smart energy system. These include smart electricity grids, smart thermal grids and smart gas grids (Lund et al., 2014). Smart grids will help in making cities more energy efficient. This will be possible through the control of distribution devices, interactions with consumers regarding energy consumption, and the electric charging of vehicles (Beard, 2016).

#### 2.3.4.5 Smart Buildings

Smart buildings include a lot of different facilities like smart homes, offices, schools, business infrastructures, data centers, factories and warehouses. Smart buildings leverage sensors and dedicated hardware and software in order to deliver to the inhabitants of a facility a certain variety of services. Among them is possible to witness the enhancement of energy efficiency through the interconnection of smart buildings with smart grids and natural energy plants. The other services guaranteed by smart buildings are related to surveillance, automated operations inside the facilities and light management (Silva et al., 2018). ICTs are an essential tool to allow smart buildings to communicate with devices located inside them, but also with the outside world. One of the core features of a smart building is building automation: sensors, actuators, controllers, central units, an interface and a network that permit to the inhabitant of a building to program the building behavior based on its necessities. Another important feature of smart buildings are smart meters that permit to the

inhabitant of the building to have information about energy consumption and billing information (Morvaj et al., 2011).

### 2.3.5 Impact of 5G in Smart City Ecosystems

Among the applications that 5G will bring to the market we can include high-reliability and low latency. These features will surely be useful to measure, control and monitor smart objects within smart cities (Alam, 2019). 5G will be crucial to allow more data traffic in the future and the implementation of M2M (machine to machine) sensing devices (Fettweis & Alamouti., 2014). The improvements made to the network through 5G such as ultra-low-latency and high reliability find their fertile ground in hybrid networks that connect machines to humans. An example of these hybrid networks are the smart cities that, thanks to their infrastructure, bring together human and machine generated data traffic (Condoluci et al., 2015).

5G will have an impact in most of the actual components of a smart city. In smart transportation 5G will enable vehicle features like passenger infotainment, driving assistance, detection of critical safety situations, augmented reality simulations for delivering precise information on what the driver is seeing and remotely controlled self-driving vehicles. Rao and Prasad (2018) in the article "Impact of 5G Technologies on Smart City Implementation" explain how thanks to low latency 5G will enable Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications. 5G will strongly impact the healthcare sector. Thanks to its low latency, which can arrive up to 1ms, telesurgery with robotic instruments will be possible and doctors will perform operations virtually from everywhere in the world. Since 5G can support higher frequencies thanks to its higher bandwidth, it will enable biomedical sensors to send a wider amount of information. Smart gadgets like wearable sensors, medical tools and monitoring gear will benefit greatly from this improvement (Ahad et al., 2019). 5G will have also a great impact on the smart energy sector. In particular regarding the smart grid, 5G will boost some applications like supervisory monitoring, fault localization and energy re-routing due to low latency, high availability and more security in the network. 5G will also have an impact in the massive IoT applications related to smart metering in order to provide the customer with better information regarding the energy that is consumed. On top of that 5G will enable the smart electric vehicle charging thanks to the low latency and quick response that is able to provide (Leligou et al., 2018). 5G technology will also have a strong impact on smart homes. In particular, artificial intelligence together with IoT will be used within smart buildings to facilitate the implementation of intelligent services in the field of heating, security, lighting and entertainment (Skouby & Lynggaard, 2014). Electricity and water consumption will be improved thanks to a more accurate monitoring system (Yassein et al., 2017). Rao & Prasad (2018) in their article "Impact of 5G Technologies on Smart City Implementation" explain that thanks to the substantial improvement in device connectivity, speed and low latency, resulting from the introduction of 5G, it will be possible to make homes safer thanks to surveillance systems. In addition, 5G will allow a large amount of data to be collected in homes, improving the energy consumption of houses.

## 2.4 Summary of the Literature Review

In this section the researcher has decided to create a summary of the literature review in such a way as to make it clear and explicit that it will be useful within the research. In particular in section 2.1 it emerged that in order to function properly and effectively 5G technology will need to meet requirements such as increased data capacity, reduced latency and reduced energy consumption. 5G technology will impact many industrial sectors and social phenomena such as healthcare, manufacturing, entertainment, automotive, energy, public transport, agriculture, public safety, megacities and smart cities. In particular, there are particular use cases in which 5G can contribute more with its innovations. These include massive IoT, time critical communication, mobile connectivity, vehicular communication and network operations.

In section 2.2 the researcher analyzed in detail the theory of business ecosystems. A business ecosystem consists of a series of actors that through their contributions in terms of value proposition collaborate together to the realization of the final value offer. The elements that make up a business ecosystem take precise names within business ecosystem theory. The *actors* are the companies participating in the ecosystem. These include the *focal firm* and the *complementors*. The focal firm is the company that assumes a predominant position within the business ecosystem and the complementors are all other companies that contribute to the realization of the final value offer. In this case more than the focal firm, the researcher decided to focus on the final value offer for the consumer, which in this case consists of the smart city. The actions that are carried out by the various companies involved in the business ecosystem for delivering the final value proposition are called *activities*. The *components* constitute the contributions in terms of goods or services that the complementors realize for delivering the final value proposition. If a component turns out to be poorly performing and blocks the entire realization of the final value offer, it takes the name of *bottleneck*.
Two different strategies can be adopted to study business ecosystems. One, called *ecosystem strategy* focuses on the stability or not of the relationships that are created between the actors of the ecosystem. The ecosystem strategy is characterized by the study of the *alignment of partners, complementarities* and *interdependencies*. The other, called *bottleneck strategy* focuses on identifying and overcoming components that have insufficient performance (bottlenecks).

In section 2.3 the researcher talked about the phenomenon of the smart city as a business ecosystem. In particular, it emerged that at the theoretical level there are many studies that define the smart city as a business ecosystem and that within this ecosystem there are a series of actors who contribute to the realization of smart solutions (the smart city components). Smart solutions contribute to the realization of the final value offer of the smart city. Among these components the most important are smart transportation, smart healthcare, smart energy, smart buildings and smart mobility. It has also emerged that 5G technology can have an important impact on these components, in particular by improving performance in terms of lower latency and high reliability.

# 3 Methodology

*This chapter presents information about the methodology used to conduct this research. In detail, the researcher's choices regarding research strategy, research design, research methods, data analysis and research quality are explained.*

## 3.1 Research Strategy

Research strategy can be of two different types, quantitative and qualitative. The type of strategy to be selected depends on the research problem and the purpose of the research analysis (Creswell, 2014). Since the purpose of the research is to investigate whether bottlenecks exist in the smart city as a business ecosystem and whether they can be solved through the use of 5G technology, the use of a *qualitative* research strategy seems to be the most suitable for the purpose.

Qualitative research is characterized by the fact that it emphasizes words rather than numbers and quantification of data. Qualitative research in fact allows the researcher to obtain opinions, points of view and reflections of respondents regarding a specific topic. Moreover, through an epistemological position called *interpretivism*, it places the interest in understanding a specific subset of the world around us through the analysis of the opinions that the participants in that subset have (Bryman & Bell, 2011). The interpretivist approach is in line with the research question. In fact, through this approach it is possible to understand which are the personal opinions and ideas of the participating actors in a given phenomenon of the society around us, contrary to the quantitative approach which is more aseptic and standardized (Hammersley & Campbell, 2012).

Another characteristic of qualitative analysis that fits well with this kind of research is that of *constructivism*. This consists of an ontological position that perceives a certain social phenomenon as the result of interactions between different individuals (Bryman & Bell, 2011). Since this research is based on the concept of Smart City seen as a business ecosystem, its focus is not on the individual actions carried out by the individuals in the ecosystem, but on the offer of final value that comes from the interaction between the various actors that make it up.

This type of research can also be considered as *exploratory*. In fact, since there are no studies on whether and how 5G can solve bottlenecks within a smart city seen as a business ecosystem, in order to obtain satisfactory answers it is necessary to obtain different opinions, considerations and perspectives from all those who can be considered experts in the world of smart solutions (smart buildings, healthcare, mobility etc..) and from the world of mobile technologies. In order to obtain relevant information, the researcher has to obtain in-deep

answers from the respondents. In fact, only by doing so can interesting developments and possibilities for relevant insights and reflections emerge.

The approach chosen by the researcher was *inductive*. It foresees that new theory can be generated from observations and findings made by the researcher (Bryman & Bell, 2011). Nevertheless, the inductive approach has some characteristics of the deductive approach. In fact, very often qualitative research does not lead to the definition of new theories and very often uses the pre-existing theory as a background for the qualitative investigations that will be made (Bryman & Bell, 2011). The use of a "spurious" inductive approach that also includes the use of elements of the deductive approach is traced back to the way in which the investigation was conducted within this research. In particular, the focus of the literature review is on three topics 5G, business ecosystem and smart city, which were not linked in other studies, but which in this specific case provided an important cue for the choice of respondents and the nature of the questions to be asked during the data collection.

Although qualitative research is the most suitable to carry out this type of study, it is necessary to take into account the limitations of this type of approach (Bryman & Bell, 2011).
In particular, the researcher may be subject to certain bias related to his or her subjectivity and personal decisions made during the research, such as the choice of respondents to collect data. In addition, a qualitative study may be difficult to replicate because the results obtained depend predominantly on the interviews carried out. In addition, since small samples are chosen to collect data during the research process, qualitative research can lead to the generalization of results. But since within the research we will focus on a single case, the objective is not to generate a general theory, but to investigate what are the opinions and ideas about a phenomenon involving a limited number of actors.

## 3.2 Research Design

According to Bryman and Bell (2011) the case study research design allows a detailed and specific analysis of an event, person or entity that is the subject of the research work. In particular when we refer to the term *case*, it is associated to a system or entity with a precise purpose and defined functioning parts. Another characteristic element of the case study is that the phenomenon studied must be limited to a specific geographical area of interest.
For this reason, the researcher thought that this type of research design was the most appropriate for the development of his master thesis on Smart Cities as a Business Ecosystem.
The smart city consists of an entity or a system composed of several functioning parts called smart solutions. Through their contribution in terms of value offer, they allow the realization of the purpose of the smart city: the improvement of the living conditions of the citizens. In addition, the research was carried out entirely in

Sweden and more specifically in the city of Gothenburg, where the researcher collected all the information needed to carry out his work. Given the nature of the smart city as a business ecosystem, the researcher did not address respondents belonging to the same company or organization, but decided to carry out his research by addressing several companies and organizations that are involved in the development of smart solutions necessary for the proper functioning of a smart city. Although the researcher addressed several companies and organizations, they all gravitate around the smart city ecosystem and therefore the appropriate research design is the single case study.

In addition to single case studies there are four other different types of research design: experimental, cross-sectional or social survey, longitudinal and comparative (Bryman & Bell 2011).
The researcher considered the experimental design not in line with the scope of the research because this kind of research design is rarely used in researches related with business and management. Another reason why this kind of design was discarded is because the majority of the variables that are implied in business studies cannot be manipulated in order to conduct a rightful experiment. The researcher has decided not to adopt cross sectional design for the purpose of this research because it refers to a plurality of cases, while in this case the research will focus on only one case study. Furthermore, cross sectional design through its focus on the generalization of results would not allow an adequate focus on the smart city, which is one of the essential requirements for this research project. Moreover, cross sectional design is often used in quantitative rather than qualitative research. The researcher has discarded the possibility of adopting a comparative research design, in fact, having focused on the study of a single case study, the comparison between several cases is not necessary. The longitudinal research design is considered not pertinent to the research. This kind of research design requires the necessity to collect data over time. The researcher thought that this choice was unfeasible because of the limited amount of time for the research project to be carried out and also because he considered not relevant to process a data collection spread over time.

## 3.3 Research Methods

Data needed to respond to the research questions of this study can come from two different sources: primary data and secondary data. Primary data are data that are collected directly by the researcher for the first time, secondary data are data which other researchers have gathered before in order to respond to another research question and that the researcher decides to utilize for his particular study (Rabianski, 2003). In this section the methodology choices of the researcher in order to collect primary and secondary data are illustrated. In particular the researcher decided to adopt the interview process for the primary data collection and utilized the secondary data collection in order to build the literature review.

### 3.3.1 Secondary Data Collection

Hox and Boeije (2005, p.593) define secondary data as "Data originally collected for a different purpose and reused for another research question". Similarly, Rabianski (2003), defines secondary data as information collected by the researcher not directly, but exploiting the work of primary data collection that other researchers have done in different studies. In this study the secondary data collection concerns the theoretical background necessary for carrying on this master thesis and is called literature review. The researcher decided to address the secondary data collection as first instance (Bryman & Bell, 2011).

According to Bryman and Bell (2011) the literature review can be of two types: systematic and narrative. At the basis of the systematic literature review there is the criterion of exclusion and inclusion. According to which the researcher decides a priori which type of information related to a topic to use or not. The narrative literature review is used to give an overall impression of the topic and has a broader purpose than the systematic literature review.

Within this research the researcher has not adopted a criterion of inclusion and exclusion. Especially in the areas related to smart city and ecosystems. In the part related to 5G the researcher decided to give more importance to the notions concerning the applications of this technology in the business world rather than to the technical details, to which, however, some paragraphs were dedicated as they were considered necessary.

Therefore, the criterion adopted for the literature review reflects more that of the narrative typology, but the current trend is being followed, according to which the distance between the two typologies is narrowing and some of the characteristics of the systematic literature are incorporated in those of the narrative literature review (Bryman & Bell, 2011).

At the practical level, the literature review was carried out looking for information about 5G technology, smart cities and business ecosystems. Information was collected through academic papers, books and scientific and academic journals which were found from online resources. In particular, Google Scholar, the University of Gothenburg Library and the Luiss library were used.

In particular to search for suitable literature for the project, some keywords have been utilized: "5G", "5G requirements", "5G applications", 5G for business", "5G development", "business ecosystem", "ecosystem theory", "innovation ecosystem", "ecosystem architecture", "actors of an ecosystem", "smart city", "smart city components", "smart city features", "smart city characteristics", "smart city architecture", "5G and smart cities", "impact of 5G on smart cities", "smart healthcare", "smart energy", "smart building", "smart housing", "smart grid", "smart mobility", "smart transportation".

### 3.3.2 Primary data collection

Primary data collection consists in a process of gathering first-hand data by the researcher. These data come from the opinions, ideas, perceptions and scientific evidence arising from the interview process, which is the most common way to collect primary data in qualitative research (Bryman & Bell, 2011). To carry out this research, the method of interviews was selected, in particular the semi structured interviews.

In qualitative research interviews can be of two types: unstructured and semi structured (Bryman & Bell, 2011). The unstructured interviews are similar to informal chats in which the respondent has the possibility to space as he or she wants when the answers are given. Semi-structured interviews, on the other hand, present more detailed questions about a given topic, these questions are presented in the so-called interview guide (**see Appendixes**). The semi-structured interviews have been chosen within this research because they guarantee a right middle way between the possibility that the interviewee has to space and the need to obtain answers that are wide but limited to certain topics that are the subject of the study.

Given the nature and purpose of the research, the researcher chose semi structured interviews, modelled on the basis of an interview guide, as a tool to carry out his research. Since the research involves the combination of three areas such as 5G, ecosystems and smart city, the use of semi-structured interviews seemed more appropriate. In fact, they allow the respondents to space and share their opinions and thoughts with the researcher, but at the same time they circumscribe the focus of the research.

The choice of semi-structured interviews instead of unstructured interviews was dictated by the fact that the researcher already had a fairly clear focus on the topic to be analyzed (Bryman & Bell, 2011). In fact, since the research focuses on investigating whether 5G technology can solve some possible bottlenecks that smart solution providers within a smart city have to face, it seemed more appropriate to use a semi-structured interview style. Conversely, if the focus had been more generic, such as the advantages and disadvantages of 5G technology, then the interview style should have been the one of unstructured interviews.

Another reason why the semi structured interviews model was chosen is because, although the research design is that of a single case study, the researcher considered important the possibility to make a certain level of comparison between the data obtained.

The use of semi structured interviews allowed the researcher to obtain insights to answer the research question and at the same time provided the necessary flexibility in a type of research of an exploratory nature. In fact, through this methodology of interviews it was possible to obtain insights and ideas from the interviewees that

had not been foreseen. In particular, it was possible to obtain detailed answers from the interviewees, but also bringing out details that were not taken into consideration by the researcher in the first place.

The interviewees were contacted by an e-mail containing a description of the purpose of the research and an attachment with the interview guide with the questions to be asked to the possible interviewee. During the interview process the researcher first approached the interviewee asking for his consent to record the conversation. All this in order to then rewrite the recordings and analyze them clearly and efficiently.
Each interview started with a description of the purpose of the research and the topics that would be the subject of the interview. Then the researcher moved on to an introductory phase with the introduction of the company and the interviewee's role in the company itself. After this first phase the researcher proceeded with the main questions.
Due to the extraordinary situation of the COVID19 pandemic, digital interviews were conducted with the support of technologies such as Skype, Zoom and Microsoft Teams.
At the end of the interviews the researcher developed detailed and organized transcripts so that the interviewees' opinions and ideas could be easily used in the study.

### 3.3.3 Selection of cases

The selection of respondents or sampling is a fundamental element within a thesis work, because through it the researcher chooses which group of people to draw from in order to carry out his primary data collection.

According to Bryman and Bell (2011) there are two different types of sampling: probability sampling and non-probability sampling. The probability sampling, in which the participants are chosen in a probabilistic way, is suitable for research of a quantitative nature and which involves the need to administer a questionnaire to a large number of people. Non-probability sampling, in which respondents are not chosen on a probabilistic basis, is more suitable for qualitative research.
Given the purpose of the research, the researcher preferred to adopt non-probability sampling, because in order to obtain the data necessary to carry out the primary data collection and then the subsequent analysis, it was necessary to turn to respondents who had knowledge and expertise on the topics covered.

Among the different types of non-probability sampling that can be used, we find convenience sampling, purposive sampling and snowball sampling (Saumure & Given, 2012).
In particular, purposive sampling is the selection of cases and respondents in a strategic way, so that they can be relevant to answer the research question. In the purposive sampling the researcher samples with a precise goal in mind. On the other hand, snowball sampling consists of a sample creation technique whereby the researcher contacts a small group of individuals and then through them establishes contacts with other respondents (Bryman & Bell, 2011).

Within this research a mix between purposive sampling and snowball sampling was used. First of all, companies and organizations respondents belonging to the categories of those who had experience in the world of 5G, ICTs, smart cities, smart projects and smart cities solutions were chosen leveraging on FTK network and thanks to the utilization of the purposive sampling. With the help provided by FTK, it was possible to access a large number of respondents belonging to the above-mentioned categories. During the course of the primary data collection, other respondents were added to the original number thanks to the snowball sampling. That is, some of the respondents, at the request of the researcher, provided contacts in order to include other respondents in the research project.

The tables below list in chronological order all the interviewees, the companies and organizations to which they belong, the role they play, the date, type and duration of the interview.

Table 3: Respondents of various companies [public and private] – (Produced by the Author, 2020)

| Respondent | Title | Company | Date | Method | Length |
|---|---|---|---|---|---|
| **Frode Langmoen** | Technology Executive, ISV & Relations Developer | IBM | 8/04/2020 | Zoom interview | 30 min |
| **Michael Westberg** | Business Development Manager | Tele 2 | 14/04/2020 | Zoom Interview | 35min |
| **Christer Omerain** | IT Architect | Atea | 21/04/2020 | Zoom Interview | 40 min |
| **Magnus Castell** | New Business & Concept Development | Ericsson | 24/04/2020 | Zoom Interview | 50 min |
| **Andreas Dahlqvist** | Head of 5G program | Telia | 29/04/2020 | Zoom Interview | 40 min |
| **Henrik Törnsjö** | R&D strategist | Göteborg Energi (public company) | 30/04/2020 | Zoom Interview | 40 min |

Table 4: Respondents of various organizations – (Produced by the author, 2020)

| Respondent | Title | Organization | Date | Method | Length |
|---|---|---|---|---|---|
| **Anders Forsberg** | Senior Project Leader | Lindholmen Science Park | 22/04/2020 | Zoom Interview | 40 min |
| **Kim Lantto** | Digital Guru | City of Göteborg | 4/05/2020 | Zoom Interview | 40 min |

## 3.4 Data Analysis

The researcher used the *thematic analysis* as a method to analyse the collected data. The thematic analysis consists of an approach devoted to the research of recurrent patterns within the interviews that the researcher carried out as primary data collection (Vaismoradi et al., 2013).

The researcher thought it appropriate to adopt the thematic analysis because it allows to divide the information coming from the interviews into small subcategories of notions, which are easier to analyze in order to answer the research question. When the data are divided into smaller entities, the researcher is able to compare the information obtained from the primary data collection and to compare them with each other. The comparison of data becomes easier and more immediate when the information is presented in the form of quantifiable and comparable entities.

The process of thematic analysis makes use of different phases, which are necessary in order to study the information obtained. The first phase of thematic analysis consists in the creation of the “codes” or “first order concepts” and is called "coding phase". This phase consists of the first step that the researcher takes in transforming the data from the interviews into their final interpretation. The researcher applied this process immediately after the transcription of the interviews, identifying recurrent elements within the interviews that were relevant to the study carried out and the purpose of the research.

The second step is the comparison process. During this phase the so-called "categories" emerge. The categories are the result of the comparison of the various codes and the agglomeration of those with similarities in terms of meaning. At this stage the researcher has to take care to maintain the necessary connection between data and codes, so that the relationship between codes and categories is not lost during the research process (Bryman & Bell, 2011).

Once the categories have been elaborated, the researcher proceeds with their aggregation with the establishment of the " aggregate themes". A theme is an agglomeration of two or more categories, which can be used to answer our research question. The coding table realized by the researcher is visible in the ***Appendixes.*** At the end of the data analysis the researcher decided to add a set of tables for summarizing the main findings and for clarifying the results of the process (**see Data Analysis**)

During the data analysis the researcher considered fundamental not only to organize the data obtained in the primary data collection through the coding process, but also to *compare* them *with the data* obtained in the *secondary data collection*. In this way it was possible to highlight possible matches and discrepancies between the two types of data that were collected by the researcher. The comparison between the data obtained through the primary data collection and the secondary data collection is fundamental to realize a new theory through research work.

The thematic analysis is the basis of a process called grounded theory. In the grounded theory approach the data collection, the analysis and the theory eventually generated are in close correlation with each other. This method of analysis involves the generation of a new theory from the collected data and is iterative, in the sense that the data collection and its analysis proceed simultaneously, with the researcher who is called to make adjustments during the research path. The grounded theory approach is the method for data analysis that is mostly used to analyze qualitative data (Bryman & Bell, 2011).

The grounded theory approach involves the creation of a new theory starting only from the analysis of the data that the researcher has collected using the procedures of thematic analysis (Bryman & Bell, 2011). However, the researcher used a theoretical substrate. Theory concerning the characteristics of 5G technology, smart cities and in particular business ecosystems have been used to build the questions necessary to carry out the data collection through the process of semi-structured interviews. In this way also the coding process, the creation of categories and themes will be affected by the knowledge that the researcher has acquired in the literature review process. For this reason, the result of the research will aim at creating a theory that can in the most specific way possible answer the question whether 5G can solve any bottlenecks that occur in the use of ICTs by companies offering smart solutions.

## 3.5 Research Quality

According to Bryman and Bell (2011) there are several criteria according to which the quality of a business research can be established. Among these criteria we have reliability, replication and validity.

A business research is reliable when the results of the study are repeatable, is replicable when the entire research can be repeated a second time and is valid if it has integrity in the conclusions. However, these criteria are more suitable for quantitative research than qualitative research.

One possibility to develop qualitative research criteria was to take quantitative research criteria and adapt them to the research of the former type. The new criteria created are those of internal/external reliability and internal/external validity (Bryman & Bell, 2011).
Another possibility is to consider other two new criteria by which to understand whether a search is qualitatively valid or not: *trustworthiness* and *authenticity*.

### 3.5.1 Trustworthiness

Trustworthiness consists of four criteria: credibility, transferability, dependability and confirmability.
Credibility is the extent to which research results can be considered credible and accepted by the rest of the scientific community. In order for the results to be considered credible, the research must be carried out according to good practice (Bryman & Bell, 2011).
To meet this criterion, the researcher has carried out a detailed literature review. Subsequently, in the transcription phase of the interviews, which took place immediately after they had been carried out, the researcher paid attention to integrate them with any notes taken in the margins during the process. Furthermore, during the interview process, if some questions were not clear, the researcher reformulated and repeated them so that the answers could be understood in the same way by all the different interviewees, in order to obtain more credible findings.

Transferability takes into account the problem of generalization within qualitative research. It consists in the possibility to extend the findings obtained in a given context to other realities different from the one taken into consideration. Transferability is one of the main problems within qualitative research, since qualitative research mainly takes into account small groups, it is difficult to achieve transferability of results to other groups. The researcher tried to increase the transferability of the result as much as possible by selecting companies from different industry sectors but related by the development of smart solutions.

Dependability consists of a process of tracking all the research stages. In order for the research to meet this criterion, it is necessary for the researcher to adopt an auditing approach, during which all phases of the

research are documented, starting with the formulation of the problem, the selection of participants, the primary data collection and data analysis (Bryman & Bell, 2011). To do this, the researcher documented in detail all the choices made during the project, starting from the definition of the research question and the problem setting (**see Introduction**), describing the methods used **(see Methodology**), transcribing in detail the results of the interviews carried out (**see Empirical Findings** ) and the analysis of data (**see Data Collection).** The same approach was adopted in the conclusions (**see Conclusions**).

According to the criterion of confirmability the research carried out must be objective. The researcher must therefore ensure that his or her work is not influenced by personal values or inclinations that may in some way affect the detachment and neutrality needed to do critical work. The researcher, despite his strong interest in the subject of the study, has therefore remained impartial during the process of data collection and analysis taking into account all positive and negative opinions about the subject. In this way, the work has been detached from the researcher's personal ideas about the subject under study.

### 3.5.2 Authenticity:

Authenticity consists of five different criteria: fairness, ontological authenticity, educative authenticity, catalytic authenticity and tactical authenticity (Bryman & Bell, 2011).

The criterion of fairness consists of the need, in order for the research to be qualitatively relevant, to take into account different points of view within the phenomenon being researched (Bryman & Bell, 2011). The researcher tried to respect this criterion by taking into consideration several respondents from different companies, who contributed to the findings of the research through their different opinions and considerations.

The criterion of ontological authenticity consists in having to contribute, through the research work, to provide a clarifying vision of the social context being studied (Bryman & Bell, 2011). The researcher has contributed to this, thanks to the ability to take into account different points of view regarding the world of smart cities seen as business ecosystems and the impact that 5G technology can have on it.

The criterion of educative authenticity consists in the ability of the research to allow the components of a given social context to consider the viewpoints of the other components of the same social setting (Bryman & Bell, 2011). The researcher interviewed different companies, and the results of the research work were shared with the various companies that were the subject of the study. In this way they could compare the opinions of the other participants and educative authenticity was respected.
The criteria of catalytic authenticity and tactical authenticity consist in the ability of the research to give input to the members of the studied social context to implement changes in their way of relating to that context

(Bryman & Bell, 2011). These criteria have not been fully met due to the limited nature of the research project in terms of time and scope of the data collected.

# 4 Empirical Findings

*In the empirical findings section, the researcher reported the data collected during the interviews. This data was collected and transcribed following the outline of the interview guide (**see Appendix**) which in turn was built on the most important aspects of the literature review. When transcribing the data, the researcher decided to summarize it so that it could be more easily readable and analyzed later. The data collected are reported in different paragraphs corresponding to the various companies and organizations that have been interviewed. Each paragraph is divided in two sections. The first one concerning ICTs currently used in smart cities for delivering smart solutions and the second one concerning possible bottlenecks deriving from the use of such technologies and possible solutions deriving from the use of 5G technologies. In particular, the section concerning the limits of the current technologies and the possible solutions brought by the use of 5G have been grouped together in order to report in a truthful way the logical reasoning of the respondents who have released information on the two aspects in a joint and therefore inseparable way.*

## 4.1 IBM

***ICT tools for delivering smart city solutions:***

There are lot of different things in which IBM is involved regarding smart city solutions, one of the main solutions utilized is the IBM cloud. When IBM deals with smart cities the company depends on the utilization of sensors. IBM both takes care of sensors and utilizes the data that is coming out from them in order to do analytics to prove something or to do something better. IBM also provides maintenance solutions and real cloud IoT.

One of the projects in which IBM is involved regarding smart cities is the “Lost Mile Transportation”: this project involves product delivery in big cities in which the number of cars that can enter the city center is limited. IBM wants to create a green and sustainable transportation model, because nowadays there are polluting tracks that are coming inside cities in order to deliver only one package. Another area in which IBM is involved is circular economy. In particular they are involved in a project called “Food trust”. In this project which is made in collaboration with Ericsson and with the utilization of 5G, IBM wants to deal with the food waste in a smart way. Food packages are tracked with 5G and moved around with a sustainable and green transportation system. Another project in which IBM is involved regards the creation of a “Digital Twin” which involves the smart building area. The aim of the project is to reduce the energy consumption inside

buildings and to track down the movement of people and goods in order to reduce the impact on the environment of the city.

***Possible Bottlenecks in the ICTs and eventual 5G solutions:***

One of the major problems with these projects are the rules and regulations imposed by the city government and the lack of information sharing between the companies that are involved in the delivery of goods. With 5G you could reduce the number of trucks that circulate in the cities and as a consequence the pollution generated will drop down. 5G could be a gamechanger because of the bandwidth and the amount of data that it can send. In particular the usage of sensors today is limited and expensive, like for example in the delivery sector. Thanks to 5G the cost of the sensors could go down, because a sensor cannot be too much expensive if you put it on a package. 5G will also influence the bandwidth and the data that you are sending in the network, because with 3G or 4G it is limited how much data you can send. With 5G you can send a lot more data. But of course, you have to build up the infrastructure, and the infrastructure is not there yet.

These projects are proof of concept projects. From 6 months to 1 year, IBM is going from the proof of concept stage to a more production oriented 5G stage. IBM is working a lot with partners in order to build an ecosystem of 5G services and 5G systems and solutions. They are at the beginning of the 5G era, because there is the lack of infrastructure. There are silos of 5G areas: for example, you have a small spot in Gothenburg in the middle of the city that runs a 5G network and maybe a small spot outside of Stockholm. So 5G has a very limited testing capacity. IBM wants to use 5G for its projects but since there is this lack of infrastructure, they are feeling some limitations. The characteristics of 5G can be useful in the implementation of IBM projects like the “Lost Mile Transportation” or the “Food Trust”. 5G solves problems related with the fact that there are a lot of data that are coming out faster. So, 5G will manage to back up this need of performance. When these projects, that are still in a pilot phase, will become bigger, there will be the need of processing more data and in order to do so 5G solutions will be needed, because it is not possible to do it with 4G. In the 5G development there could be some problems in defining a common standard, for example if I want to send something from country A to country B, also the 5G network in Country C and D need to be developed. In order to make 5G work there should be a unified network. The infrastructure is fundamental, so in order to make the 5G real, the network as to be developed in the greatest number of countries as possible. Also, the cost of 5G is an important variable to take into account, it will be used if it costs less that 3G or 4G or other kind of solutions. If 5G is going to be too much costly nobody is going to use it. 5G is going to provide a better value, but at the moment between 4G and 5G you can still use 4G because of the lack of implementation that 5G is facing. At the moment IBM is using 4G, but in the future 5G is going to add better value in terms of speed and capacity and IBM wants to be there.

## 4.2 TELE 2

***ICT tools for delivering smart city solutions:***

Smart city has wide range of use cases. You can't build a smart city without telecommunications.
One use case is traffic management. Another use case is the energy sector where we have early stage connectivity to electricity meter and the grid. In this area we will see a lot of more sensors and a lot more and improved connectivity that will massively improve our ability to handle the energy systems coming up. Since we are going towards renewable energy, you need to have a lot of more information from the electricity grid. Cars, transport and the industry are more and more going towards electrification. Having a huge reliance on electrification means there will be new requirements on the grid and you also need to have a much more connected grid. When you look at a smart city, we have to take into consideration the so called Massive IoT (so the presence of lot of sensors, very high bandwidth and low latency). Is good to have 5G when it comes to massive IoT because it brings new capabilities, but when it comes to ordinary communications the 4G level of communication is probably sufficient for most of the use cases.
If you look at the main uses in smart society, Tele2 is looking at the energy sector in terms of smart grid and smart metering and at the automotive sector in terms of fleet management and also connected cars.

***Possible Bottlenecks in the ICTs and eventual 5G solutions:***

One of the issues faced with actual ICT solutions is the issue of coverage both in remote areas and in cities. There are issues with connectivity because there might be no coverage out in the wilderness. If you look at the city there is always an issue of coverage indoor and in the basements. So, if you want to put up sensor systems or even reaching people for example in the basement there are some problems because radio signal doesn't penetrate.
There are real issues in Smart Cities scenarios when you have a large number of sensors in a small area because the current mobile system is not really built for large number of sensors, devices, subscribers in a really small area. The number of devices will drive signaling. Signaling is always a bottleneck. There are clear issues when you have a concentrated number of devices in a very small area. That's where 5G and the massive IoT technologies have some real benefits, because they are designed in order to have a much larger number of devices in a small area. Today we do not have these problems, because we do not have so much density of devices, but there are issues when devices are multiplying, and people are using more data. These issues are part of the smart city scenario when you are connecting a lot of smart vehicles in the city and when you have high concentration of those. A lot of the 4G functionalities will be migrated into the 5G, so in some cases there are disruptive changes from 4G to 5G while in other cases is just a transition. Examples of 5G applications are automated vehicles, 5G in healthcare, 5G in smart industry with industry 4.0 and in building and construction. 5G together with private networks will have an impact in a wide range of industries ranging from massive IoT

(so very large number of sensors and devices- hundreds of billions of connections) to critical 5g applications (with really low latency and very high reliability).
5G applications range from very high bandwidth applications such as AR, VR to very low bandwidth applications when we look at this massive number of sensors. 5G standard is rolling out in the first step right now in the market, it has not yet deployed it in Sweden because the 5G auctions are going to take place in November, Once the 5G auction has been done there will be a quite rapid rollout of the 5G system across Sweden.
Talking about automated vehicles we need 5G in order to have the latency that is required. If you look at self-driving cars and self-driving busses, they will of course have sensor systems that will make them automated, but you will have a great benefit if you add connectivity with low latency, that will make it even better. These kinds of solutions will be much better implemented with 5G rather than 4G. You can speed things up a bit or do intervehicle communication that can optimize the traffic, and, in this case, you really need the really low latency that it's provided in 5G much better than 4G.

5G will be useful for the fast response, it will be important in the V2V (vehicle to vehicle) and V2X (Vehicle to Everything) communication, which is optimizing the way the traffic flows between the vehicles. So, you can signal when you go through a crossroad when you have the red lights having different cars that can communicate with each other and this will make the traffic flow much better.
If you want to do direct vehicle communication, without going up in the network the utilization of 5G could be very interesting. Most of the 5G functionalities that will apply to V2X and smart industry are not really available yet. We are in really early days of live applications and no one knows how 5G characteristics will be used. It will take 1,5/2 years before we see 5G on the market, people are still looking to find how to utilize 5G, how to deploy it.

If you do not have a complete end to end ecosystem 5G will not arrive in the market, the first thing that you need is a network, you need 5G terminals, 5G capable routers, and capable devices that have to be competitive in terms of pricing. When you see 5G devices at prices that match the use cases that's when you will see the take off. And this take off will vary depending on the use case and the industry. There are always competing technologies, like for example wi-fi 6, that is competing a complementing 5G.

## 4.3 ATEA

***ICT tools for delivering smart city solutions:***

In order to have a smart city you need to have a setting of different types of smart buildings. A building is considered smart if it can be controlled and adjusted by the user, can provide information to the user and can learn, adopt and adjust to the user/tenant habits. These three features are essential in a smart building, but also in a smart office and in general in a smart city. If you can't provide a service that respects these three characteristics it is just a technical evolution, but it has not to be considered smart.
In order to make the smart building real, the contribution of a company like ATEA, which has experience in IT solutions is fundamental. Atea is interested in smart building, because they offer ICT solutions, they are consultants in this area, they are interested in the smart office area, in networking and security, in datacenters and edge computing and AVK (Atea Video Communication).
Atea utilizes different ICTs for businesses implying Smart City solutions, they collaborate with a company called ACCESSBOLAGET to deliver ICT solutions specific for certain regions and areas in Sweden.
The ICT solutions utilized varies depending on the region, but in general they are:
SDWAN, GSM 3g/4g, Van länkar ,Blackfiber ,VPN solutions, Firewall,NAT,Load balancing,PSec VPN,SSL VPN-Plus,Static & Dynamic Routing,DHCP,Internet access or WAN. These solutions are provided not only by ATEA, but from a plethora of different vendors that need to collaborate in order to provide the right combination of ICT solutions that companies need.

***Possible Bottlenecks in the ICT and eventual 5G solutions:***

At the moment there are no drawbacks in the actual ICT solutions utilized for delivering the smart value proposition of Atea. The technologies needed right now are sufficient, but in the near future when we will have for example driverless busses for commuting you will need the data processed nearby the bus, this will be a driver for the 5G, because you will need to send a bigger amount of data in a rapid way not as we do today with 4G. In the future we will see the demands of that. But right now, the data needed today can be provided with the actual technology.

A smart building has to be able to adapt to the end customers, it can learn the customers behavior and it could change the set of rules automatically depending on what is optimized for the customer. In order to do that I need machine learning and AI platform.

Digitalized healthcare will be one of the areas affected by 5G. Especially in those functions that are extremely data driven. For example, the technology to perform the scanning is easy, but the optimization for processing the data obtained is a key feature that is not provided by the utilization of 3G or 4G, it takes too long and it is

not reliable. Everything in healthcare will be related to remote visits and remote surgery. We could get more reliable ill examinations. It will reduce the costs and the time implied to obtain a medical response.

Another sector that will be influenced by 5G is self-automated transport. As long as I have a function that has to be data processed, I have a problem with the actual ICT solutions. In the smart building word 5G will bring benefits in all the functions that require low latency, high capacity, high bandwidth, the need of sending signals quick, and critical IoT applications. For example, the surveillance and security of smart buildings will be affected by 5G because low latency and fast response is required, and this is not provided by the actual ICT solutions.

5G will make it easier to provide the needed service without the need of building the infrastructure every time I am offering the service. 5G will have an impact on delivering services that are more environmentally friendly and will boost the economy. Self-automated transport and digitalized healthcare will arrive in the future, because now there is a lack of infrastructure that could support 5G network.

For a company like ATEA, that provides infrastructure as a service the benefit will be the better utilization of datacenters.

The arrival of 5G could influence the business of datacenter. Everyone talks about using the cloud, but not everyone can use the cloud today. 5G could make possible the utilization of the could for the companies that can't do it at the moment. This will be one of the biggest impacts of 5G.

Every company that is involved in building servers and storage will be impacted by 5G. They will see a rapidly decreasing market, because their products will not be used like before.

In general, the number of sensors adopted will increase considerably in the future, but in the smart building sector the number of sensors will decrease. The key of a smart building is integrating the technology that is implied. Today there are separate sensors for humidity, for temperature, and for people counter. But these sensors are going away, because we will use for example only one camera in order to get the information needed. We are going to decrease the number of technical infrastructures within the smart building. I am putting less sensors, but I am adding complexity because I need less technology in order to process all the information needed. This process will be data-driven, the amount of data will decrease, but the need for data process management will increase. There will be less data, but it will be more challenging to process the data. There is the need of edge computing in order to carry out this process, because I need to process data in the building. In particular I need to send data directly to the cloud because I need really complex calculations. For example, if with a sensor I can measure the temperature inside the building, I can adjust it taking into account the temperature outside, the direction of the wind and the people inside the building.

Now edge computing is utilized, but if 5G had been developed before it could have been utilized in order to carry on this process instead of edge computing. If there wasn't the legacy of edge computing I could have

utilized 5G in order to do that, because thanks to it the sensor could talk directly with the computing part within the could.

## 4.4 LINDHOLMEN SCIENCE PARK

***ICT tools for delivering smart city solutions:***

A smart city is a connected and sustainable city from a transport system perspective. The Dencity project is focusing very much on electric vehicles, sustainable road transport, sustainable water transport, waste and recycling material from the households.

Dencity is a specific project within the Closer program consisting in a floating moveable center for taking care of electric waste. It focuses on goods and personal freight transport. The Closer program also focuses on micro hubs, geofencing (you can take control of the truck from the manufacturer and you can set the limit of speed when for example you are in a walking zone. You can also remotely control the route of the trucks for security issues). In this area the 5G could be very useful.

5G could be very useful for self-driving vehicles, but in present existing solutions there aren't so much existing applications.

Dencity is a lot about transport efficiency, sustainable and green logistics and also the reducing of traffic jam in the city center. They need to trace parcels, to know where the parcels are in their flow from the webstore to the customer. They are still struggling to get access to transport data, which is essential in order to build transport efficiency. Even if they are not still utilizing ICT solutions now in the project, when the project will be scaled up in the near future, they will need connected vehicles that will run on 4G.

***Possible Bottlenecks in the ICT and eventual 5G solutions:***

In the next phase of the project, in which self-driving vehicles will be implemented, 5G will be essential and extremely important, because without it we will not be able to implement them. You need low latency to be capable to remote control the vehicle, which is provided thanks to 5G.

5G could be also a useful for tracking parcels. So, once the sharing of data from the freight companies is obtained with 5G it will be possible to track the packages in real time and to know where they are in a precise moment.

Regarding the waste management and the smart buildings 5G could have a strong impact. The Closer program runs a project called "Full-Service Estate", in which you bring the customers goods from the vendor to their door thanks to smart locks and doors. This project has potential in the implementation of smart home. 5G could have potential from a business perspective and from a smart home/ smart building perspective.

One of the characteristics of 5G is that you can augment the number of sensors utilized and you can process a larger amount of data in the short time because of the high capacity. These characteristics of 5G can be useful in the moment we witness a horizontal flow of information.
In the present phase 4G is good enough, but 5G will be very important when dealing with self-driving vehicles considering the low latency challenge.
In Dencity, the government, the academy and the enterprises are working together. In the next phase of Dencity more technologies that enable sharing of data, positioning of parcels have to been taken into account. For example, there will be the implementation of microchips and antennas.
The most common partners in the project come from the logistic sector, from the traffic department in Goteborg and Stockholm, the academy like Chalmers University. In the next phase there will be more companies that are involved in communication technology, to ensure that the parcels are connected, in order to enable the optimized flow of parcels.
In this phase of the Dencity project they rely on 3.5G and 4G. But in the next phase 5G can be useful to ensure the creation of sharing of transport data to optimize the flow of goods.

## 4.5 ERICSSON

***ICT tools for delivering smart city solutions:***

In the access to the network Ericsson is working with 5G. Both what is called non standalone 5G and standalone 5G. They also work with 4G, both with mobile broadband 4G (the normal 4G networks) and also the IoT access types (narrowband IoT and Massive IoT). But they also utilize Lora (Long Range) and Wi-fi for indoor or very low performing sensors. They also utilize LTE-M.
They also have applications in the mobile edge computing which are very close to the users, especially applicable for high performance low latency applications for automotive or industrial IoT.

Ericsson is involved in a variety of projects regarding smart cities. Starting from projects that involve very low performance sensors that measure something and give back data every month to the industrial IoT in which real time data is an important feature. Ericsson works in logistics and surveillance using drones. In drone machine control, they are focused on how drones can fly and operate individually but also in a fleet while controlled remotely. Ericsson works a lot with the automotive sector in order to develop capabilities for autonomous driving or teleoperations, which regard the remote control of vehicles that are connected to 4G and 5G.
They are working also in Mobility as a Service, that is how you can utilize carpooling and car sharing and how you can provide data to the user for smart routing for going from point A to point B, involving public transportation, taxies, scooters, rental bikes. They are working with agriculture, in one project in particular

they are connecting beehives with cameras in order to monitor the health of the bees, since they are very important in the food production. So, they can measure everything from heat, humidity, pests in the hives or diseases. Urban farming is a big project that is focused in the utilization of spaces in the city for growing plants and food indoor with to use the AI (artificial intelligence) and machine learning for determining everything from nutrition of the plants to lighting. They are involved in healthcare, in particular to make sure that doctors and nurses are sanitizing their hands. They are involved in measuring water currents and salt levels through the utilization of sensors attached to seamarks.

For most of these projects, since they do not require real time and critical response, 4G is being utilized. For real time critical projects like teleoperations or remote controlling Ericsson is using 5G. All depends on the time criticality and the amount of data that the sensors are generating. For example, in object tracking there is a lot of data and very low latency requirements so now 5G is used. For just measuring and send data from sensors, 4G is utilized because these are not time critical applications and there are not so much data to be processed. The data volume and the latency are the factors that determine if 4G or 5G are going to be utilized. If there is the need of low latency and a lot of data volume 5G is utilized instead of 4G because the previous generation of mobile connectivity system can't provide these requirements.

***Possible Bottlenecks in the ICT and eventual 5G solutions:***

At the moment Ericsson is not facing a lot of issues with their ICT solutions, because most of the projects that require 5G features are still in experimental phase. But if these projects are going to be scaled up for a commercial use, then there are some problems with the actual ICT solutions.

The most important problems that Ericsson is facing are related to the fiber backbone that we have today, there could be some glitches, some congestions, some delays due to the infrastructure that is used for commercial use. Other problems are related to performing in an effective way the projects that were explained before, because you need both political and regulatory approval. For example, relating to self-driving vehicles, you can't do it everywhere, you need approvals and permits that could take a really long time. In fact, it's quite hard to get the politics and the regulators on board to get the right approval to perform trials and innovation projects.

Another thing that Ericsson is facing is the lack of 5G modems and devices, they are too few at the moment and the quality is not that good because it is a new technology. For 4G is much better. But on 5G Ericsson can leverage on few modems and devices that are useful for their projects. Another problem that is seen is how to get funding for small projects and startup companies that imply 5G technology. Big companies can easily apply for funding from the European union for projects related to 5G technology. But for the small companies

with which Ericsson is collaborating for projects related to 5G technology it is difficult to obtain the funds. So, these projects could end prematurely because of the lack of money.
Technically with 5G we are at the start, so there are a lot of technical challenges, but it will be a good roadmap for when new functionalities come into place. The problems related to 5G are to be found typically outside the domain of Ericsson: infrastructure, political regulatory willingness, funding and devices.

There are various sectors that could leverage much more with 5G, especially the automotive domain. In particular when it comes to autonomous drive and teleoperations. Teleoperation is adopted mostly by professional users of heavy trucks and construction equipment. In a smart city when it comes to data sharing and sensor sharing in a traffic situation, when vehicles have to share their data with other vehicles. In particular while sharing video and their position, when different vehicles should enter in an intersection. For smart logistics and smart city perspective we will gain a lot with 5G, that was no possible to achieve with 4G, like in the cases cited before. In fact, there will be much more data generated, computed and consumed in a short time, short distance and small geographical area. So, with 5G and edge computing we will see a lot of gains in the traffic authority domain. In healthcare, we will also see huge differences when it comes with remote surgery, remote monitoring of people. It will require high data volumes and low latency, and with 5G these applications in the medical sector will be possible, while with 4G these applications can't run properly. We will see a big change also in the gaming industry, when you will be able to use quite small consoles, consoles that don't need to be wired to the computer. You can play with them and have all the gaming engines in the cloud close to you. You can play much more sophisticated games. Also, the tourism industry will be affected by 5G, for example with the AR (Augmented reality). Also, the drive experience will be affected by 5G. The augmented reality will also be a game changer when it comes to 5G, because you will be able to leverage much more on that compared to 4G. There will not be any drastic or complete new domains coming up with 5G, but there will be the enhancing of the existing ones, in which you will be able to do much more in shorter time delays with 5G. In general traffic, healthcare, gaming and all the experience industry when it comes to AR and VR will be affected by 5G.

The smart grid (regarding to the energy sector) today is mostly handled with fiber connectors, but maybe later on removing the cables and going over air you could have much more flexibility of the measuring sensors and switches. So maybe this could also be an area in which 5G could have a strong impact in the future.
The high bandwidth, the low latency are the typical uses cases for 5G, when you go up in frequency. Those now will only be available in small areas where you can have better performance, large bandwidth and low latency. Also, high coverage will be important. In fact, 5G will not only enable low frequencies, but also high frequencies and this will enable large coverage for IoT services. It could be really useful for smart metering and tracking devices that do not require so much data but require high coverage. So 5G will leverage on both the low frequencies, large coverage and also high performance with smaller coverage.

The authorities and the regulators are both working on spectrum on the high band and in the mid bad (where we have 3G and 4G) with a technology called spectrum sharing. With the spectrum sharing you can start developing 5G services on 4G spectrum. Massive IoT will be affected by 5G in uses cases that require a really low latency and a really low spectrum. It will cover a wide range of use cases in the future.

Thanks to these applications in the IoT word 5G can have applications in the smart city word, quick and critical response and late response when you collected data about consumption and pollution will be guaranteed by 5G. Not in the first moment but only later on.

In the Dencity project Ericsson was involved in logistics services and lost mile delivery. In particular regarding how to operate both pods and drones in order to carry out packages and removing garbage.
The aim of the project was to create a zone in the city with no cars and no parking spots. Ericsson was involved in finding a solution for having a good distribution of mails, packets and goods. Also, the removal of waste was one of the desired outcomes of the project in which Ericsson was involved. The discussion was related on how you can utilize 5G in order to have semiautonomous pods and drones. Also, there was a focus on smart lockers, and how can use personalized codes in order to have your packages delivered to you. In particular the focus was on managing to sense the space available in the locker, so that the locker could send information to the vendor or supplier. In this way the locker could send information to the supplier or vendor, telling him for example to not delivery because the locker is full.

Talking about the lost mile delivery and its logistic and mobility, 5G will have a vital role when it comes to remote controlling of vehicles, but also being part of the autonomous system in which this pods and drones should act in. 5G will be a vital part of this revolution. The difficulties with this are more on the positioning and localization services, because since we are working in a very dense area with high buildings, the GPS signals are very weak, so it is very hard to position yourself in that kind of area. So, the question is if through 5G we can use the cellular technology for more precise indoor location, without that we cannot work with the pods or drones, because in the Dencity project you always have to know where the pods and drones are. So, handling this in a dense area is a challenge. In cities with very high buildings the positioning is very challenging, and this will be the challenge also of the Dencity project.

Regarding the pods and the autonomous vehicles involved in the project, if you have them in autonomous mode (which means they have a pre-downloaded map) and they have GPS, cameras and radar to determine where they are, 4G technology will be enough to make them work. But the problem is that the road is not static, there could be a dog or a pedestrian that approaches the car and the vehicle has to change road very quickly. In this case you need to know where you are using positioning so you can stop or go around the

obstacles. It is important to enhance safety and avoid incidents. In this case you will need 5G and maybe to switch to remote controlling with teleoperations of these vehicles. Because you need someone that is responsible for the vehicle if something happens. So, you can drive autonomously with 4G in very low speed, but if something happens out of the ordinary you need to take over, then you need 5G, because otherwise with 4G there would be too much latency and congestion in the network. So, as a safety feature 5G is needed.
For more efficiency and more safety reasons 5G will bring those capabilities that 4G cannot deliver today.

Nowadays the focus is more towards industrial applications and vehicles and transportation.
The closest thing to smart city is the traffic management so how vehicles can communicate in intersections, roundabouts and so on. But this is a small part of a smart city.

## 4.6 TELIA

***ICT tools for delivering smart city solutions:***

Telia utilizes different kinds of services and ICT solutions that are important for the smart city development. The first one is called “Crowd Insights”, based on the traffic on the mobile network that is present in a certain geographic area. They can do an anonymous analysis about how people move and act within the city during certain times of the day. Having the data analytics from the mobile infrastructure is fundamental. Telia also leverages IoT business for connecting public transport, they have lot of sensors to understand how a facility is working and what type of conditions are in the smart city in order to collect information. These are commercial offerings, but they are also working a lot on innovation in the smart city sector, for example in the support of electrical vehicles, connected vehicles, positioning and augmented reality to enhance experience within a city. Telia is involved in a lot of projects and collaborations. From the mobility perspective they are working with several actors for improving connected and autonomous public transport leveraging IoT for collecting information. In the IoT area they are working with energy companies for smart meters and making energy consumption efficient. They are also working with few real estate companies for the development of smart buildings and they have also innovation projects regarding digital healthcare with their partners, especially in the public sector. These projects are driven by mobile connectivity and IoT.
The biggest issue faced in the smart city projects is to bring all the different smart solutions together as an ecosystem in order to bring value to the end user. Telia has one of the best 4G network in the word and in the various projects in which Telia is involved 4G has demonstrated itself capable, in particular in relation to the IoT use cases. So, they believe there are no boundaries in the performance of 4G that make them think that they will need 5G in the short term.

***Possible Bottlenecks in the ICT and eventual 5G solutions:***

5G is useful if you want to scale up the use cases that were explained before. For example, 5G will be needed in relation to the autonomous vehicles when you need the processing of lots of data for real time video streams or for the development of super dense IoT sensors, because 4G will not be capable of supporting such applications. But at the moment the 4G network has been sufficient. 5G will be useful for autonomous transport when you need high reliability and low latency video stream and control of the vehicle. Regarding smart healthcare there are limitations of 4G related to positioning in the network. 5G will have a better support for positioning in the mobile network and will be one of the key drivers for 5G technology. Positioning means being able to position people and do asset tracking. You can track how people and goods are moving in a city. It could be useful if you want to limit the transition of people and vehicles in green areas or for example in the city center. You can also track down the equipment, so you do not lose it. In this case it could be useful in the healthcare sector.

Telia is participating in a project called "Digital Demo Stockholm", it is an innovation cooperation to enhance citizens in Stockholm region with digital solutions. Autonomous transport, surveillance, vigilance analytics will need 5G for their development. Also, the implementation of augmented reality within a city will require 5G. Also, if there is a rapid growth of the amount of data in the network, that will be a driver for the growth of 5G. Regarding Autonomous transport and Augmented Reality 5G will bring something that 4G can't. In particular reliability, low latency and uplink bandwidth. 5G will also bring new possibilities in terms of network slicing.

5G will be useful to solve coverage issues. This will happen inside cities, but also outside. For example, Telia, in collaboration with other companies like Volvo, Ericsson and Boliden collaborated in the "PIMM" project. The main aim of the project was to bring mobile connectivity underground in a mine. With 4G signal this is impossible, but with 5G the problem is solved. 5G could solve problems of coverage in cities, for example in the underground.

Since 5G is a completely new technology on the edge to be mature you will run into technology issues, into issues related to the network that has to work in collaboration with the devices, issues will be also at the standardization level. 5G and 4G will coexist but will have different applications and use cases. Not in all cases 5G will be utilized, that's because also some of the ICT solutions that are currently utilized will have implementations that will boost their performance, for example the wi-fi and the 4G technology. Not all the new use cases will be applied to 5G, some will still run of 4G.

Also, the switch between 4G and 5G will not happen immediately, but it will take time. In fact, there will be a gradual substitution from 4G to 5G. The driving force for 5G applications in the industrial world will be the critical IoT. The digitalization of society and industry, where you can use new types of network services which are more robust and reliable, will be one of the main drivers of 5G applications. Automotive, manufacturing, healthcare and mining industry will be among the sectors that will be strongly affected by 5G. Since in these

sectors you need a stable, robust and high performing foundation for digital transformation they can utilize the 5G network for a wide set of different applications. If people will start utilizing augmented reality on a wide scale, they will need low latency and high bandwidth for high quality stream. This could be a driver for 5G, because 4G is not actually capable of providing this kind of service. 5G will be a smarter technology that will consume energy only when it is required. 5G will be part of the digitalization of society and will have an impact on sustainability. In terms on a smart city 5G will be part of the various technologies that are utilized within a smart city.

## 4.7 GÖTEBORG ENERGI

***ICT tools for delivering smart city solutions:***

Göteborg Energi has different solutions relating to smart energy, like district heating and electrical systems. The first smart solution introduced by Göteborg Energi was the smart metering in the grid.
The ICT solution linked with the smart metering is the so called "SCADA" system. The first kind of sensors utilized by Göteborg Energi for metering, could send data every hour, one or two days after the power was delivered. One of the challenges is to implement a "SCADA" system that is connected, real time and high security protected. Independently of the technologies utilized like Zigbee or 4G, the issue of security is for sure one of the most important. Another issue is related to cost: the ICT solutions to be implemented have to be cheap. 5G will solve the problems related to security, it will be faster, but it won't be cheaper. The respondent doesn't see ways in which 5G could benefit the smart grid apart from the security area, because there is not the need to have really fast data collection. In order to actually benefit the smart grid industry, really good business models have to be developed. The smart grid actually leverages on a combination of fiber, 4G and wi-fi. For the most critical parts, the fiber is the preferred solution. While dealing with customers, Göteborg Energi leverages on the Zigbee, which is a cheap, low power radio frequency. District heating also leverages on ICT solutions such as the fiber and the "SCADA" system and Zigbee. District heating is related with the utilization of waste heat that comes from processes carried on by factories. Datacenters produce a lot of heat while they process their function of data storage, the heat produced by them can be utilized in the district heating system. In district heating, Göteborg Energi would like to control the customer side of the process, that is concerned with the distribution of the district heating to houses.

***Possible Bottlenecks in the ICT and eventual 5G solutions:***

In the smart grid, there is a criticality in the smart maintenance area. It is an area that needs a lot of sensors, in order to detect fallacies and problems in the system. This area will leverage a lot on ICT solutions. You need a lot of sensors to track how the smart grid is working and having a lot of sensors means having a lot of data that have to be processed. For example, AI (artificial intelligence) will be important in this area. There is both

interest in the number of sensors and the data management. In the smart maintenance there is a need for more sensors and the implementation of AI. These needs cannot be completely satisfied by with 4G. 5G will for sure deliver a better service, it will deliver more security and protected data, but the problem is that it could be too much costly. There could be also problems related to building of an optimized network for running the 5G frequencies everywhere. Another problem of implementing 5G solutions in the energy sector is the need for a stricter collaboration with the telecommunication sector. Actually, the smart grid works with the fiber when it needs a high and fast response. The 5G could bring the capacity of processing data and having a fast response even further. Having a better coverage could be useful in the smart grid, but since the equipment utilized by Göteborg Energi is stable and not in movement 4G technology provides a sufficient coverage, especially in the city. If you have a grid in the country, when you have long distances and high mountains that are blocking the signal, 5G could be more useful than 4G. Göteborg Energi has a lot of personal that goes around the city by car in order to fix the grid for doing smart maintenance, in this case the utilization of augmented reality for working in real time can be really useful and 5G could have an impact and deliver solutions that 4G cannot provide. In this case 5G can be useful for bringing low latency and the capability of processing a huge amount of data faster in order to make faster decisions. In this way the staff that is involved in the maintenance can work more efficiently.

The Hz frequency in the grid goes up and down really fast. In order to make this process more efficient there is the need for planning times when the infrastructures have to shut down for having a smoother process. If you have to measure the Hz frequency in the net in a really fast way you need the implementation of 5G for having a quicker response. The optimization of the Hz frequency is useful for the implementation of the frequency market where you actually sell and buy energy.

District heating is another area which will imply smart solutions in the energy sector. At the moment they are just measuring, and it is not a real time process, the next step is going into real time. The benefits of introducing 5G in this case regard the optimization of the system and the smart maintenance side of the district heating. With the introduction of 5G these things will be done with much more efficiency. For example, thanks to 5G it will be possible to do remote maintenance if there are some problems in the house of the customer related to the district heating distribution to homes. 5G will be also useful for monitoring the consumption habits of the customers. For the security issues related to the district heating system, the need for having a fast and quick response is real and having a low latency will be useful for bettering the security. The heating system is not fast at the moment in terms of the response. The issue of security is more important in the smart grid and having a low latency and fast response will be of fundamental importance. Also, in the datacenter business, the security issue is fundamental, because if the datacenter goes down there will be a loss of data and money for the companies that are storing the data. Even in this field having a fast and quick response is fundamental in terms of security.

## 4.8 CITY OF GÖTEBORG

***ICT tools for delivering smart city solutions:***

The city of Göteborg digital department works with a lot of different ICT solutions for delivering services. They utilize the LoRa network for measurement devices that could send data, wi-fi for the collection of data, 3G and 4G for digitalized water and waste collection and fiber is used in every building that in some way is supplied by the city. For specific smart city applications, they work with some projects like the "Lov-IoT" project where simple devices are utilized for measuring air quality with the participation of citizens. Goteborg Energy leverages on the wi-fi connection that people have in their home for collecting data, through sensors that sense which is the air quality within the building. Another project that is going on right now is the Digital Twin project. The city will utilize it for planning house building and restructuring. The city wants to use it has a communication tool with the citizens. The are other projects which are based on data sharing. Some of the networks of the City of Göteborg are used by Volvo for vehicle gridding and for collaborations with the city and the traffic department. In the water and waste management wi-fi, LoRa and 4G are mostly used. In this case, the traffic of data doesn't demand the utilization of 5G technology, because they are light data and not heavy. If sending pictures or doing live streams or capturing videos were part of the water and waste management, it could have been different and 5G could have been required.

***Possible Bottlenecks in the ICT and eventual 5G solutions:***

The traffic of data right now is light and doesn't demand high data processing, but if there were more data implied, since 5G is faster and provides more data it could have been implied. But in the water and waste management there is not technical maturity to utilize 5G solutions. If 5G was announced today, the water and waste management sectors would imply from three to seven years in order to utilize this kind of service because these sectors are really traditional in the way they work. They wouldn't be the ones that test 5G solutions in their sectors, they would utilize it only in the moment in which it is tested and tried out efficiently.

The ICT solutions utilized today like the LoRa, wi-fi and 4G are sufficient for the needs of this the moment. In their everyday service there are no bottlenecks that the city of Göteborg reports. In the buildings where high-performance traffic is required, this demand is guaranteed with exclusive fiber because of security issues in particular related with the water management sector. Taking in consideration garbage trucks you could give a better service if you had better performance, so 5G could be useful for bettering the service that the truck provides at the moment.

In particular, it could give to the city of Gothenburg more information, because trucks will be able to collect more information and send them back thanks to the utilization of cameras and objective distancing systems. At the moment, trucks are working sufficiently well with 4G because they are utilizing only frames of pictures and positioning sensors that do not require a lot of data processing. But in the future if the service is

implemented it could require 5G. In the automotive sector and in specific companies like Volvo, the utilization of 5G technology could be more useful and more immediate in the near future. The city is not mature enough to use it today.

The garbage trucks are only collecting garbage, but they could generate a lot more data and services to the city. For example, they could give information regarding the situation of the road and the traffic. But in order to implement 5G in a sector like this, expertise inside the companies is needed. You need people that are able to leverage the 5G technology in order to utilize it in the best way possible.

Regarding the issue of security, the city or the police could benefit from the utilization of 5G solutions. Tracking people and traffic and using data for the security system can be one of the fields in which 5G could perform better instead of 4G.

Cities in Europe have several problems regarding the kind of services that they manage to deliver, so before implementing 5G solutions inside the cities, they are giving priority to deliver a better service for the citizens. 5G in the future could be useful for collecting a huge amount of data from cars. It could be useful for bettering the traffic management system inside a city. But the techniques that are utilized today are sufficient for what the city asks for at the moment.

In the search and rescue area, there will be the need of instant data traffic and instant cameras and instant recording will be utilized. The fire department of the city, the ambulances and the police are those who need fast data and extreme security. In this case 5G has to provide them a specific channel for data collection and communication because these data need to be private and not shared. Regarding the healthcare sector, 5G will have applications in the elderly care, where you need robots that guarantee a fast and immediate response that 4G cannot deliver. One issue related with 5G is the cost. the city is willing to take an investment in 5G only if it costs less or the same as the old technologies that are utilized.

# 5 Data Analysis

*Within the data analysis the researcher used the coding process in order to reorganize the data of the primary data collection into themes. Subsequently, these themes were compared with the primary data collection in order to find correspondence or not between the literature review and the data collection. In particular, the author has divided his work into five main sections: the first section concerns smart solutions, i.e. the components of a smart city. The second section concerns the ICT tools utilized for delivering smart solutions. The third section concerns mobile technology future bottlenecks. The fourth section concerns the Smart Solutions actual performance with the ICTs utilized and the future ICTs bottlenecks. The fifth section concerns the solutions that 5G can provide for these possible bottlenecks and the sixth section concerns general limitations for the implementation of 5G technology. Each section created by the researcher corresponds to an aggregate theme that has been identified through the coding process (**see Appendixes**). The fourth section is the result of the combination of two different aggregate themes, namely the "smart solutions actual performance with ICTs" and "Future ICT bottlenecks in the smart solutions". The researcher decided to merge them in the data analysis to make the discourse homogeneous as they are closely related. To see how the two sections have been developed, please refer to the **Appendixes** where the coding process is illustrated.*

## 5.1 Smart Solutions

The data collection showed that all the companies and the organizations surveyed are involved in the development of Smart Solutions. Some of them are among those included by the authors that the researcher examined in the section of the literature review dedicated to smart cities. Others, on the other hand, present new insights into the various complementarities and components of the smart city ecosystem.

### 5.1.1 Smart Transportation

One of the smart solutions that emerged from the data collection is smart transportation. Silva et al., (2018) state how the introduction of smart transportation within cities can have an impact on the improvement of public transport service, on cost reduction and on increasing security. The comparison of the respondents' answers showed how companies that are confronted with this type of smart solution, focus on other aspects such as reducing emissions and vehicle circulation in order to create a green and sustainable mobility system for goods and people. In this field IBM is particularly active. Through the project "Lost Mile Transportation" the company aims to create a green and sustainable transport, acting on the logistics and delivery sector in order to reduce the number of vehicles entering the city center and reducing emissions. Similarly, the Lindholmen Science Park through the "Dencity" project, which is part of the "Closer" program, aims to create a sustainable city from the transport system point of view. In particular, the project aims to create a green and sustainable logistics by reducing the traffic inside the city center.

Another substantial difference between the primary and the secondary data collection regarding smart transportation can be seen in the solutions planned to develop a smart transportation system. Both IBM, through another project called "Food Trust" and the Lindholmen Science Park through the "Dencity" project, have demonstrated their intention to establish a smart transportation system through the tracking of parcels that are delivered within cities. Unlike them Agarwal et al., (2015) focus on a series of tools necessary for the implementation of the smart transport system. Among these we have the smart parking management system, the intelligent traffic management and control system, the safety management and emergency system and the smart pavement management system.

### 5.1.2 Smart Buildings

Another of the smart solutions that is mostly pursued by the companies interviewed is the creation of smart buildings. According to Silva et al., (2018) the smart building concept extends to a large number of buildings such as houses, offices, infrastructures, data centers, factories and warehouses. Smart buildings use sensors to ensure that those who live in smart infrastructures benefit from a range of services. In particular, the services offered include security, automation and lighting management. The data collected by the interviewees shows that a lot of companies are involved in developing smart building solutions. Among those there are IBM, Atea, Lindholmen Science Park, Telia and the City of Göteborg. These companies have as their main interest the reduction of energy consumption and environmental impact, the ability to adapt to the tenants' habits, the improvement of the delivery service for the inhabitants of the buildings and the continuous communication with the citizens. In particular it turned out that both IBM and the City of Göteborg are engaged in the realization of a "Digital Twin" project. IBM in particular embraces this project to reduce environmental impact and energy consumption, while the City of Göteborg emphasizes that the creation of a "Digital Twin" is of fundamental importance to manage urban development and communication with citizens.

### 5.1.3 Smart Mobility

According to Olaverri-Monreal (2016), Autonomous Vehicles are one of the main concepts within the smart mobility domain. Thanks to the use of technology a smart vehicle is safer, consumes less energy, reduces environmental impact and provides a better entertainment experience inside the vehicle. These notions related to smart mobility are reflected in the data collected by the researcher. In particular, both Telia and Ericsson are involved in autonomous driving. The former is working with many actors in order to improve connectivity in autonomous public transport, while the latter is developing autonomous driving capabilities in relation to remote control of vehicles. Ericsson is also strongly engaged in mobility as service and car sharing by implementing smart routing for public transport, taxis, scooters and rental bikes. This particular focus of the Swedish company is reflected by Pangbourne et al., (2018) according to which mobility as a service is one of the predominant concepts within the smart mobility domain, and by Li and Voege (2017) according to which

the car sharing system is one of the case studies of smart mobility applications, as it aims to reduce the costs and environmental impact of vehicles by replacing private transport with a public access-based system. Comparison of the data provided by respondents also showed that there is a trend towards electrification of vehicles in the mobility sector. In particular Tele2, Lindholmen Science Park, Telia and the City of Göteborg expressed an interest in the electrification of the mobility sector. In particular both Tele2 and the City of Göteborg highlighted how electrification of urban transport can be one of the solutions implemented by traffic management. It also emerged that both Tele2 and Telia underline the importance of their contribution towards the implementation of connected vehicles.

### 5.1.4 Smart Energy

According to Beard (2016) smart grid will be relevant to make cities more energy efficient. The importance of the smart grid is also underlined by Lund et al., (2014) according to which it will form the foundation of the smart energy system. Comparison of the data from the interviews showed that Tele2 and Göteborg Energi have a strong interest in the development of the smart grid system. Both companies refer to the need to adopt a smart metering system within the grid. In particular Tele2 refers to the need to implement the number of sensors and connectivity of the grid so that it can provide more information. Göteborg Energi points out that the first smart solution they adopted was smart metering within the grid.

According to Telia, smart metering will also be essential to achieve an efficient energy consumption system. In particular Tele2 considers the phenomenon of renewable energies, highlighting how they will require a greater contribution in terms of information regarding the electricity grid. This concept is expressed in an almost specular way by Lund et al., (2014) which not only emphasize the importance of the smart grid, but also assert how it will be fundamental for the use of renewable energy. Discrepancies between primary data collection and secondary data collection concerning smart energy have emerged in the focus that is made by Göteborg Energi on district heating, which according to the company is one of the sectors that will be most affected by smart solutions in the energy field.

### 5.1.5 Smart Healthcare

The comparison of the answers obtained by the interviewees showed that Ericsson and Telia are the two companies that emphasize the importance of smart healthcare. In particular Ericsson emphasizes Teleoperations, i.e. remote operations carried out through the remote control of machines. This concept is partially reflected in Baker at al., (2017) according to which one of the most important applications within the smart healthcare domain is remote healthcare monitoring, which can be used to visit patients remotely and to reduce the number of staff in the hospital. Telia, on the other hand, focuses on the innovation projects that the company is pursuing with its public sector partners for the digitization of healthcare. Silva et al., (2018) agree

that smart healthcare is a combination of traditional medical practices and the use of ICTs, sensors, smartphone applications, wearable devices, cloud computing and fog computing.

### 5.1.6 Other Findings

Comparing the data obtained through the interviews, the researcher also noted the existence of other areas where companies think that the use of smart solutions is relevant and that have not been examined in the secondary data collection. In particular, it emerged that IBM, Lindholmen Science Park, Göteborg Energi and the City of Göteborg are both focused on the development of smart solutions for waste management. IBM in particular focuses its attention on food waste, Göteborg Energi on waste energy. Lindholmen Science Park and the City of Göteborg focus on improving the current waste collection and disposal system. The former trying to introduce a sustainable way of waste disposal, while the latter trying to digitalize the ways in which waste is collected.

It has also emerged that many companies have an interest in their smart solutions being safe and reliable. For example Atea is involved in the surveillance and security of its smart buildings, Lindholmen Science Park in the Dencity project claims that remote vehicle control will have a positive impact on security in the city, Göteborg Energy claims that some of the ICT applications used can have a positive impact on security within the smart grid and Ericsson is developing a drone-based surveillance system. given the evidence demonstrated through the comparison of the interviews, the researcher considered it appropriate to designate two new areas of interest called *smart security* and *smart waste*.

## 5.2 ICT tools for delivering smart solutions

The analysis of the data collection showed that all the companies interviewed use ICT technologies to create smart city solutions. In particular there are some ICT solutions that are used by most of the companies. Among these we have technologies related to the world of mobile connectivity such as 3G and 4G technology. The importance of the use of these technologies is reflected by Tudzarov and Gelev (2017) who highlight how, thanks to the introduction of 3G technology, it has been possible to bring wireless broadband on the market while through 4G technology consumers have been able to benefit from the first mobile broadband. Another widely used technological application is the Internet of Things (IoT). The data collected showed that the Internet of Things is one of the most widely used tools by the companies surveyed to develop smart solutions. The importance and relevance of this technology is highlighted by Mumtaz et al., (2017) who describe the IoT

as the result of the interconnection of smart devices, which facilitates the creation of an interconnected world. All companies that include the use of IoT among their ICT tools also mention the use of sensors for data collection and monitoring. The use of sensors as an ICT solution is underlined by Lu (2017) according to which they will be fundamental to allow the integration of complex machinery and devices and to plan future developments of the businesses whose resources are monitored. Similarly, the importance of sensors is highlighted by Rao and Prasad (2018) in the article “Impact of 5G Technologies on Industry 4.0” according to which sensors will play a predominant role in the implementation of industry 4.0 and the smart factory.

The various companies and organizations examined as the subject of the research have shown that the ICT tools currently in use are varied and remarkable. Among these, there are many technologies that are generally not very performing, but which are used because they meet the cost efficiency criteria of the companies examined. For example, LoRa (Long Range) modulation technology is used by high-tech companies such as Ericsson and by companies that do not have technology as a core business such as the City of Göteborg. In the same way the simple wi-fi connection is an ICT solution adopted at the same time by Ericsson (a developer in the world of telecommunications), Telia (a provider), Göteborg Energi and the City of Göteborg which do not have as their core business connectivity or telecommunications.

All the ICT solutions mentioned earlier are used by at least two of the companies considered. The research has shown that there are ICTs that are only used by some companies and therefore only in those sectors that they represent. In particular, it emerged that the companies where technology is the core business, are those that adopt the most ICTs to develop smart solutions. Ericsson is the only company that uses 5G technology as current information communication technology to develop smart solutions. In particular the Swedish company uses two different types of 5G technologies, i.e. non-standalone and standalone. In addition to these solutions is adopted edge computing, artificial intelligence and machine learning. Atea adopts a large number of ICTs to develop its value proposition and in particular it has emerged that the ICTs used vary from region to region. These include: SDWAN, Van Lankar, Blackfiber, VPN solutions, Firewall, NAT, Load Balancing, PSec VPN, SSL VPN-Plus, Static & Dynamic Routing, DHCP, Internet access or WAN. Furthermore, the company does not provide all these solutions alone, but in collaboration with other vendors. It also emerged that in the energy sector, represented by the company Göteborg Energi in this research, ICTs that are not adopted by any other company or organization are utilized, among them we have the "Scada" system and the Zigbee. Telia also uses a technology that is not used by the other interviewees, the so-called "Crowd Insights".

## 5.3. Mobile Technology Future Bottlenecks

Through the process of thematic analysis, the researcher has identified how companies and organizations interviewed, despite being partially satisfied with the current use of ICTs in the domain of mobile technology and in particular 4G technology, will face bottlenecks in the future. Among these we have the categories of *Data Capacity*, *Coverage* and *Sensors* (see the table of coding process in the **Appendixes**).

### 5.3.1 Data Capacity

A comparison of the data obtained from the interviewees showed that the ICT most widely used for smart solutions is mobile connectivity and in particular 3G and 4G technology. Comparing the data obtained through the interviews carried out by the researcher, it emerged that many of the companies and organizations interviewed are sufficiently satisfied with the current performance of 4G technology. However, it was repeatedly pointed out that in the future 4G technology will no longer be able to adequately meet the demands in terms of performance due to the evolution of the value offer made by the companies and organizations surveyed. One of the future bottlenecks identified regarding this type of technology and which is a common theme for many companies is the lack of adequate data capacity.

According to Tele2 when it comes to ordinary communication services, the service offered by 4G technology is sufficient in most cases, but when there will be an increase in the number of smart devices used by consumers, 4G will not have the necessary capacity to process the amount of data required. By comparing the data from the secondary data collection, it is possible to establish how the data capacity is a technical bottleneck and more specifically a flow bottleneck. According to Baldwin (2015) a technical bottleneck occurs when there are performance deficiencies that have not yet been overcome and that slow down the ecosystem. In particular, a flow bottleneck consists of a technical bottleneck that finds its criticality in the lack of an adequate level of capacity.

### 5.3.2 Coverage

Another of the bottlenecks related to the use of 4G technology is the one related to coverage. In this case both according to Tele2 and Telia with the current 4G technology there are coverage problems inside cities and outside the urban context. On the contrary, according to Göteborg Energi the coverage guaranteed by the 4G service is sufficient inside the city because it is used to connect not moving devices that the energy company uses. Again, a flow bottleneck is faced. In fact, the descriptions of the problems related to the performance of 4G in terms of coverage coincide with the definition of technical bottleneck and flow bottleneck given by Baldwin (2015).

### 5.3.3 Sensors

According to IBM the current use of sensors undoubtedly constitutes a bottleneck within the ecosystem of smart cities. In fact, the use of this technology is too limited and expensive, moreover, from a technical point of view the sensors have some critical issues when connectivity is needed in places far from repeaters, such as basements. Tele2 pointed out that there is a problem of sensor performance when there are too many sensors concentrated in a small area within a smart city. In this particular case it emerged how the high concentration of sensors in a small space can generate "Signalling" problems. Again, we are faced with a flow bottleneck. In fact, the descriptions of the problems related to the performance of sensors coincide with the definition of technical bottleneck and flow bottleneck given by Baldwin (2015).

## 5.4 Smart Solutions Actual Performance with ICTs and Future ICT Bottlenecks

Through the thematic analysis it emerged how companies and organizations involved in developing smart solutions within the smart city ecosystem are satisfied with the current performance of ICTs used today, especially 4G technology. Moreover, it has emerged that by the time companies and organizations themselves will decide to better and upgrade their smart solutions, the current ICTs will no longer be sufficient to perform this task. In fact, the thematic analysis revealed four main categories that constitute the future bottlenecks that will occur in a cross-sectoral way in the use of ICTs in the areas of Smart Transportation, Smart Building, Smart Mobility, Smart Energy, AR and AI. These categories are: *Data Generation & Data Processing*, *Low Latency & Fast Response*, *Security* and *Bandwidth* (see the table of coding process in the **Appendixes**)

In the following sub-paragraphs the researcher analyzed how, for each of the smart solutions that have been identified, the current ICT solutions are performing adequately and how in the future the categories of *Data Generation & Data Processing*, *Low Latency & Fast Response*, *Security and Bandwidth* will constitute bottlenecks across all these smart solutions.

Therefore, the following paragraphs deal exhaustively with the current level of satisfaction in the use of ICTs and the emergence of future bottlenecks for each of the major smart solutions in the categories that have been identified.

### 5.4.1 Smart Transportation

IBM has stressed that at the present time for the realization of their projects, the use of 4G technology is sufficient, but in the future, when there will be the need to have more data processed, 4G will no longer be a valid solution because of the limited amount of data that can be sent and the speed with which data are processed. Also, the Lindholmen Science Park is facing some issues with their smart transportation solutions

utilized in the Dencity project. They focus on goods and personal freight transport and in delivering transport efficiency through a sustainable and green transportation system. They need to track parcels and to establish a delivery system based on self-driving vehicles for the next phases of their project. At the moment they are working fine with the actual 4G technology, but in the future this technology will not be enough for tracking parcels and for delivering boxes with self-driving vehicles. Also, Ericsson which is involved in the smart logistics sector thanks to its collaboration with the Dencity project is performing well with the actual ICT solutions because at the moment there are no time critical applications and the number of data processed is still relatively low, but in the future when it will be necessary to process more data 4G will no longer be enough. In particular since the Swedish company has the vision of utilizing pods and drones for smart logistics in this project and they are not sure if 4G will be enough for delivering these advanced smart solutions.

### 5.4.2 Smart Buildings

From the data collected through the primary data collection it emerged that in the smart building sector the companies involved in the development of smart solutions are satisfied with the use of current technologies, in particular 4G technology. However, it emerged that in the future when further implementations of this smart solution will be required, 4G technology will no longer be sufficient. According to Atea, current ICTs and in particular 4G technology will no longer be able to provide the low latency and fast response necessary to guarantee surveillance and security inside buildings. Likewise, IBM and the City of Göteborg, which are currently engaged in Digital Twin projects, are satisfied with the current use of ICTs for the implementation of these projects. However, IBM has pointed out that in the future the number of data that can be processed using 4G technology will not be sufficient for the further development of its projects, including Digital Twin.

### 5.4.3 Smart Mobility

Comparison of the data obtained through the interviews showed that the current ICTs and in particular 4G are considered to be sufficiently performing in terms of smart solutions related to the world of smart mobility. However, it also showed that when the various projects and solutions that include smart mobility will move to a later stage that requires more performance from the technology currently used, 4G will not be sufficiently performing.

In particular, both Tele2 and Ericsson highlight how the use of 4G technology is currently sufficient to have a basic level of automation in vehicles. Tele2, Lindholmen Science Park and Atea, on the other hand, point out that when it comes to self-driving solutions, the performance of 4G technology will no longer be sufficient. Ericsson makes a similar speech of the other companies and organizations pointing out that when vehicles will need a real-time response with low latency to ensure an adequate level of safety and efficiency 4G cannot be enough. Telia and City of Göteborg point out that when more data will need to be processed in vehicles than is currently the case, the characteristics of 4G technology will not be sufficient. In particular Telia stresses the fact that regarding autonomous transport 4G is lacking reliability, low latency and high bandwidth.

### 5.4.4 Smart Energy

In some cases, respondents have stressed that they are perfectly comfortable with the use of 4G technology without mentioning possible lack of performance due to future developments of smart solutions. In particular Göteborg Energi pointed out that they do not find any problem with the use of ICT solutions such as fiber, 4G and wi-fi with regard to the implementation of the smart grid. Göteborg Energi does not find any performance problems with the current use of fiber, in particular for smart grid solutions, where it is used for more critical solutions because it is considered reliable. One branch of the smart energy sector in which bottlenecks are being found is the smart maintenance branch. In fact, to adopt smart maintenance solutions within the smart grid it is necessary to implement augmented reality solutions and increase the number of sensors present within the grid. But this is not possible due to the technical limitations of 4G technology.

### 5.4.5 Smart Healthcare

By comparing the data obtained through the interviews, it emerged that there is another area in which the use of current ICT solutions and in particular 4G can constitute a bottleneck, namely healthcare. According to Atea and Ericsson, 4G will not be sufficient to carry out extremely data driven healthcare applications. In particular, according to the Swedish telecommunications company 4G will not be able to guarantee to remote surgery and remote monitoring of people because it is not able to offer real time and critical response in the field of teleoperations and it is not capable to guarantee high data volumes processed and low latency. According to Telia, there are limitations of 4G with regard to network positioning.

### 5.4.6 AR and AI

Another area of technological application where 4G will not be sufficient to provide sufficiently adequate performance in the future is the field of Augmented Reality (AR) and Artificial Intelligence (AI). In both these two areas the current performance of 4G technology will not be enough to meet the growth needs of these new business sectors.

## 5.5 5G solving mobile technology future ICT bottlenecks

Through the thematic analysis it has emerged how 5G, thanks to its features, is able to solve future bottlenecks that will arise in the domain of mobile technology. In the following paragraphs the researcher will illustrate how, according to the companies and organizations interviewed, 5G technology will be able to *solve* bottlenecks related to *Data Capacity*, *Coverage* and *Sensors*.

### 5.5.1 Data Capacity

5G will bring many benefits compared to 4G technology in particular with regard to the amount of data that can be processed. By comparing the data obtained through the interviews the researcher observed that 5G technology will have an important effect on the increase in data capacity, which was one of the main shortcomings of 4G technology. In particular, both IBM, Atea, Ericsson and the City of Göteborg pointed out how 5G technology can have a fundamental impact on increasing the volume of data that can be generated and processed. These observations of the respondents are reflected in the data obtained through the secondary data collection, i.e. the literature review. As illustrated by Gupta and Jha (2015) in paragraph 2.1, the data rate is one of the areas where wireless technologies have evolved over the years along with coverage and efficiency. Similarly, Singh and Singh (2012) in paragraph 2.1.2, illustrate how 5G will contribute to ensuring greater data capacity in terms of data transmission. The impact that 5G will have on data capacity is fully explained in paragraph 2.1.3.1, where according to Andrews et al., (2014) the 5G network will allow a considerable increase in data traffic. In particular, according to the authors, 5G technology will impact the data rate in three different ways. It will increase the capacity (the amount of data that the network can support), it will increase the edge rate (the worst network coverage that the consumer can experience), and it will improve the peak rate (the best data rate that a consumer can experience).

### 5.5.2 Coverage

Thanks to the comparison of the data collected through the primary data collection it emerged that according to Ericsson, Telia and Göteborg Energi, 5G will substantially improve coverage compared to previous generations of mobile connectivity. In particular, according to Ericsson, 5G will have a significant impact on coverage since it will support both low and high frequencies, and thanks to 5G technology it will be possible to solve indoor coverage problems. According to Telia 5G will solve coverage problems both outside and inside cities, in particular it will bring the signal in remote areas such as mines. According to Göteborg Energi, 5G will bring better coverage and this will have positive feedback on the smart grid. The impact of 5G in the coverage domain is confirmed within the secondary data collection. In fact, as pointed out by Gupta and Jha (2015) in paragraph 2.1, coverage is one of the areas that have been most affected by the development of wireless technologies. In paragraph 2.1.2, Singh and Singh (2012) highlight how 5G will bring much better coverage than previous generations of cellular networks. In paragraph 2.1.5.3, Chandramouli et al., (2019) highlight how thanks to 5G rural areas where there was often a lack of coverage will finally be able to receive the signal of the mobile network. In paragraph 2.1.5.5, Zhang et al., (2017) also point out that 5G will have benefits in terms of coverage in very large areas. Moreover, the authors emphasize that 5G will be fundamental to improve coverage in areas of the city where a high volume of data traffic is required.

### 5.5.3 Sensors

The comparison of the data obtained through the interviews carried out in the primary data collection showed that 5G will have a significant effect on sensor technology. In particular, according to IBM thanks to 5G technology it will be possible to reduce the cost of sensors and according to Lindholmen Science Park thanks to 5G technology it will be possible to increase the number of sensors used in order to process more data. The impact that 5G technology will have on sensors is reflected in the secondary data collection. In particular, in paragraph 2.1.3.4 Rao and Prasad (2018) illustrate how 5G among the various requirements that it must meet in order to have practical relevance in the world around us has to reduce the cost of devices in order to support the development of sensors that are battery powered. In paragraph 2.1.4, Chandramouli et al., (2019) point out that thanks to 5G the number of sensors and objects connected within cities will increase substantially. Thanks to the implementation of this high number of sensors we will be able to monitor pollution and energy consumption within our cities. In paragraph 2.1.5.5, Zhang et al., (2017) highlight how 5G networks should ensure the connection of millions of devices with a low impact on costs and energy consumption through the use of low-power sensors.

## 5.6 5G solving smart solutions future ICT bottlenecks

Through the thematic analysis it emerged how 5G will be able to solve future bottlenecks that will occur in the ICTs in order to bring to the next stage some of the current smart solutions. It emerged how, thanks to the features of 5G technology, it will be possible to solve the bottlenecks of *low latency & fast response*, *data generation* & *data processing*, *security* and *bandwidth*.

In the next sub-paragraphs, the researcher will illustrate how for each of the smart solutions considered, 5G technology will be able to solve the previous illustrated bottlenecks in the following smart areas: Smart Transportation, Smart Building, Smart Mobility, Smart Energy, Smart Healthcare, AR & AI and Massive IoT.

### 5.6.1 Smart Transportation

Thanks to 5G technology, substantial improvements in smart transportation and logistics will be experimented. In particular, according to IBM, with 5G technology it will be possible to reduce the number of trucks circulating within cities and we will see a reduction in urban pollution. Moreover, according to Ericsson, through the implementation of 5G technology within the Dencity project it will be possible to develop semiautonomous pods and drones' systems that can be used for parcel deliveries. According to the Swedish company, 5G, thanks to the increase in data capacity and low latency, will also be able to improve object tacking applications, also useful in the parcel delivery field. According to Lindholmen Science Park 5G will be useful for tracking parcels and for implementing smart delivery systems in the Dencity project.

According to Telia, 5G technology will also bring benefits in asset tracking, which will affect the smart logistics and smart transportation sectors.

### 5.6.2 Smart Building

Comparison of the data collected with respondents showed that 5G will have a strong impact within the smart building/smart housing sector. In particular, according to Atea, 5G technology will have a strong impact in the smart building sector because it will be able to bring benefits to all those functions that need low latency, high capacity, high bandwidth and speed in sending signals. In particular the surveillance and security of smart buildings will be strongly impacted by 5G technology, as it will bring the low latency and fast response needed to optimize these solutions, which could not reach their full potential with current ICTs. Also, companies such as Tele 2 and Atea stressed that 5G will have an important impact in the smart building sector. According to Lindholmen Science Park 5G will have a strong impact on the smart building sector and in particular in the "Full Estate Project".

### 5.6.3 Smart Mobility

Through the comparison of the data obtained from the interviews carried out with the respondents, it emerged that 5G technology has a very important effect in the automotive sector and in smart mobility and it can help to solve some of the bottlenecks that characterize this sector. In particular, 5G will be of fundamental importance in the implementation of self-driving vehicles, because it will guarantee the low latency level necessary to adopt these innovative solutions. In addition to low latency, 5G will contribute significantly in the smart mobility sector by providing the right level of reliability and high bandwidth. In addition, 5G will be of great importance when developing V2V (Vehicle to Vehicle) and V2X (Vehicle to Everything) solutions to exchange information between vehicles and other objects that make up the urban ecosystem. The significant impact of 5G technology within the automotive sector is underlined by Vlachos et al., (2017) in section 2.1.5.4. In the same paragraph Chen et al., (2017) highlight how 5G technology will have a very important effect in the V2X (vehicle to everything communication) sector. In addition, Chandramouli et al., (2019) emphasize that 5G is necessary when full automation in the automotive sector is necessary to be achieved. At this stage the driver no longer has to intervene on the vehicle, because everything is done automatically through 5G technology.

### 5.6.4 Smart Energy

Comparing the data obtained through the respondents' answers, it emerged that 5G technology also influences smart energy solutions. In particular it can be used to solve criticalities in the grid according to Ericsson. According to Telia, 5G technology could be useful to step up smart energy projects and could also reduce the total energy consumption, using energy only when it is required. Also, according to Göteborg Energi, 5G

technology could help to make the smart grid safer thanks to the low latency, which is essential to have a quick response if there are safety problems in the grid. Moreover, according to Göteborg Energi, 5G technology could be useful to improve efficiency in the field of smart maintenance. The influence that 5G technology will have in the energy sector is reflected in section 2.1.4 in which Chandramouli et al., (2019) illustrate how 5G technology will have an important impact in the energy sector in the fields of grid and control monitoring. Furthermore, in paragraph 2.1.3.3 Andrews et al., (2014) highlight how 5G technology will have a positive impact on the reduction of energy consumption, so as to confirm the match between the data obtained in the primary data collection and the secondary data collection.

### 5.6.5 Smart Healthcare

By comparing the data obtained by the researcher in the primary data collection it emerged how 5G has a strong impact in the healthcare sector and how it can solve some of the bottlenecks present when companies and organizations want to develop smart healthcare solutions. In particular Tele2, Atea, Ericsson, Telia and City of Göteborg highlighted how 5G applications will improve current smart healthcare performance. In particular, according to Atea and Ericsson, 5G will contribute predominantly in the field of remote surgery and remote monitoring thanks to the large amount of processed data and the low latency that 5G will bring to the healthcare sector. Furthermore, it has emerged that 5G is generally considered important for AR and VR applications in the world of medicine and care for the elderly when the support of robots is needed to ensure a fast and immediate response that 4G cannot provide. The importance of 5G in the domain of smart healthcare is reflected in paragraph 2.1.4, in which Chandramouli et al., (2019) have specified how among the various industrial applications of 5G technology one of those is the healthcare sector and in particular the development of augmented and virtual reality applications in the world of medicine.

### 5.6.6 Augmented Reality and Artificial Intelligence

A comparison of the data from the primary data collection showed that 5G technology will have significant applications in the fields of augmented reality and virtual reality. In particular, according to Tele2 and Telia, 5G technology will guarantee the necessary bandwidth for augmented reality and virtual reality applications. According to Telia and Göteborg Energi 5G technology will provide the low latency needed for augmented reality solutions. According to Ericsson, 5G technology will have an impact on augmented reality applied to tourism, gaming, healthcare and traffic.

### 5.6.7 Massive IoT

The comparison of the results obtained through the interviews also showed how 5G technology can have a strong impact in the world of IoT. In particular, according to Tele2, 5G technology will have a strong impact on massive IoT, making it possible to increase the number of devices operating within a small area. According to Ericsson, 5G technology will have an impact in the world of massive IoT ensuring a series of use cases that require low latency and low spectrum. The impact of 5G technology with respect to massive IoT is underlined in paragraph 2.1.5.1. In fact, Rao and Prasad (2018) state in the article "Impact of 5G Technologies on Industry 4.0" that 5G technology will be one of the enablers of IoT by ensuring the reliability, latency and scalability needed for massive IoT. In addition, according to Chandramouli et al., (2019), 5G will provide the security and privacy necessary for the various applications of massive IoT.

## 5.7 Limits towards 5G implementation

### 5.7.1 Lack of Infrastructure

From the analysis of the data collected in the primary data collection, some aspects emerged that the researcher had not taken into consideration as a reflection for his research work, but which are of fundamental importance and need to be explored. In particular, it emerged that the 5G technology and consequently its applications have not yet reached a mature development due to the lack of an adequate infrastructure to support them. In particular, there is not yet a network adequately implemented at national (Sweden) and international level that can allow the development of 5G technology in several countries at the same time. There are also shortcomings in terms of devices, routers and terminals with adequate performance.

### 5.7.2 5G cost issue

Another issue that could slow down the development of 5G technology is the cost. In fact, although many of the companies interviewed believe that 5G technology can bring substantial improvements in their smart solutions, they are also aware that if the price of 5G is too high, they will hardly decide to adopt this technology.

### 5.7.3 5G time issue

Another issue that can slow down the application of 5G technology is that of time. In particular, it emerged how we are in a historical moment not yet mature and ready to adopt 5G technology solutions. In fact, according to many of the companies interviewed, even if they decided to adopt 5G solutions, the results of these applications would be obtained in a period that in some cases is around two years, while in other cases

it can reach up to eight years. In many cases the current smart solutions that companies adopt with the help of 5G technology are only embryonic projects, which will have to wait a long time before they are scaled-up.

## 5.8 Data Analysis main findings

Given the length and complexity of the data collected during the research, the researcher has decided to dedicate this paragraph to summarize the main findings that will then be highlighted in the conclusions.

Table 5: Future Bottlenecks Identified in Mobile Technology – (Produced by the author, 2020)

| **Future Bottlenecks in Mobile Technology** |
|---|
| **Data Capacity** |
| **Coverage** |
| **Sensors** |

Table 6: Smart Solutions actual performance with ICTs and future ICT bottlenecks – (Produced by the author, 2020)

| **Smart Solutions Actual Performance with ICTs and Future ICT Bottlenecks** |
|---|
| **Low Latency & Fast Response** |
| **Safety** |
| **Data Generation & Data Processing** |
| **Bandwidth** |

Table 7: Future Bottlenecks solved thanks to 5G – (Produced by the author, 2020)

| Future Bottleneck | 5G Solved |
|---|---|
| **Data Capacity** | **yes** |
| **Coverage** | **yes** |
| **Sensors** | **yes** |
| **Low Latency & Fast Response** | **yes** |
| **Safety** | **yes** |
| **Data Generation & Data Processing** | **yes** |
| **Bandwidth** | **yes** |

Table 8: Limits towards 5G Implementation – (Produced by the author, 2020)

| Limits Towards 5G implementation | | |
|---|---|---|
| **Infrastructure** | **Cost** | **Time** |

# 6 Conclusions:

*In the section dedicated to the conclusion the researcher answered first the sub research questions and then the main research question using the data obtained through data analysis. In the last section the researcher illustrated some suggestions for potential future research on the topic of 5G technology.*

## 6.1 Overview

As specified in paragraph 1.2 smart cities are a current phenomenon and are on everyone's lips at the moment. Moreover, it is well known that they are made up of a set of stakeholders who all have the ultimate goal of achieving a sustainable and intelligent city. The various stakeholders that contribute to the final realization of

value (the smart city) for the consumer, constitute the ecosystem of a smart city. Many cities have been tested for the use of 5G technology in different smart solutions, like smart healthcare, smart grid, IoT and smart sensors, city surveillance, smart safety, smart mobility, smart building, smart transportation and so on.
As illustrated in paragraph 1.3, despite the fact that smart cities in the literature are defined in a direct or indirect way as business ecosystems and despite many attempts to apply 5G technology to cities, there are no studies where business ecosystem theory has been applied to the study of the effect that 5G technology can have on a smart city and in particular on the various smart solutions.
To bridge this gap, the researcher decided to apply business ecosystem theory to smart cities, focusing on the effects of 5G technology on smart solutions. In particular, the researcher focused on one of the fundamental aspects of this theory, namely the identification of possible bottlenecks (performance, capacity, scarcity problems) related to current ICTs (Information and Communication Technologies) that are adopted by the various actors of a smart city to develop certain smart solutions. Once these possible bottlenecks were identified, the researcher decided to investigate whether they could be solved through the use of 5G technology.

Therefore, the researcher decided to address the study of this topic by structuring the research in order to answer the main research question mentioned in paragraph 1.5:

*What bottlenecks in the smart city ecosystem, if any, can be overcome with 5G technology?*

To answer the main research question, the researcher divided it into two sub-research questions:

*Which are the bottlenecks of the ICT tools for delivering smart solutions?*

*To what extent can these bottlenecks be solved through 5G?*

## 6.2 First sub research question

As mentioned in the previous paragraph and in paragraph 1.5 of the introduction one of the sub research questions to be answered in order to respond to the main research question is:

*Which are the bottlenecks of the ICT tools for delivering smart solutions?*

Through the research carried out, important considerations have emerged regarding the bottlenecks of the ICT tools used to create smart solutions. An important fact is that the companies and organizations examined are generally satisfied with the current performance of the ICT tools, both in terms of mobile technology and smart solutions.

In particular, it emerged that in the mobile sector the current 4G technology has satisfactory levels of performance, especially with regard to the basic communication service guaranteed by this technology. With regard to smart solutions, in the areas of smart transportation, smart building, smart mobility and smart energy, the current technologies, and in particular 4g technology, can adequately fulfil their task and are therefore are sufficient to implement smart solutions at a basic level. For example, object tracking in smart transportation, the basic automation of smart buildings, vehicle automation in smart mobility and the implementation of current smart solutions involving the energy sector are all smart solutions that are satisfied by the actual performance if the ICTs.

Despite this, it has emerged that with regard to mobile technology and smart solutions, current ICT solutions will not be sufficient for future developments and will therefore constitute a bottleneck.

In the domain of mobile connectivity three main bottlenecks will emerge **data capacity**, **coverage** and **sensors**. It has emerged that current technologies, and in particular 4G technology in the future, will not be able to provide sufficient data capacity when demand for data will rise due to the increase in the number of connected devices. In the same way 4G technology will experience performance problems related to the coverage needed both inside and outside the cities. In particular, when it will be necessary to bring connectivity to areas outside the city center, such as the countryside, 4G will not be able to provide the necessary level of coverage required.
Another criticality will be found in sensors. In fact, when it will be necessary to increase their number and concentration in small areas, the current use of 4G technology will not guarantee satisfactory levels of performance. Moreover, due to the lack of adequate connection capacity of the sensors far from the repeaters, their installation in places far from the connection sources will not be possible with the current ICTs. At the moment the only way to install sensors in new areas is to install a new repeater and this is expensive.

In the domain of smart solutions, the ICT bottlenecks that will emerge in the future will be multiple. The researcher identified four main bottlenecks that will be found when smart solutions are implemented and current smart projects are scaled up: **data generation & data processing**, **low latency & fast response**, **security** and **bandwidth**.

In smart transportation, smart healthcare and smart mobility, 4G technology will not be able to support future demand for *processed and generated data*. Especially in smart transportation, when more data production and processing will be needed to track objects, 4G technology will not provide the required support. In smart healthcare the demand for data collected and processed to obtain patient information will not be matched by

the current performance of 4G technology. In smart mobility, when vehicles will need to collect and process more data than current 4G technology, actual 4G technology will lack performance.

*Low Latency*, i.e. the low delay between the generation and process of an input, is one of the fundamental requirements of all those smart solutions that need a *fast response* to perform their task in situations that require criticality and immediacy. Through the analysis carried out it emerged that in the future, when smart solutions will be implemented and brought to the next stages the low latency required will not be supported by current technologies and in particular by 4G technology. In the smart healthcare sector, the current 4G technology will not be able to provide the necessary real-time response for the applications concerning remote surgery and remote monitoring of people. Likewise, in the smart building sector, the 4G technology will not be able to provide the low latency and immediate response necessary for all those applications concerning surveillance and security within smart infrastructures. In the smart mobility sector, current ICTs and 4G technology will constitute a future bottleneck because they will not meet future requirements in terms of low latency and critical response. All the applications concerning self-driving vehicles will not be realized without being able to benefit from an immediate and real-time response. Likewise, in the smart transportation sector, 4G technology will not be able to support future demand for speed and low latency, as for example in the autonomous transport applications.

Another future bottleneck of ICTs utilized to develop smart solutions is the one related to *Security*. In fact, it has emerged that 4G technology will not be able to guarantee the necessary level of security when smart solutions projects will be implemented. In particular with regard to the smart building sector, 4G will not guarantee the necessary security within the connected infrastructures. In the smart mobility sector, especially with regard to autonomous vehicles, 4G technology does not guarantee a necessary level of safety so that a remote-controlled car will not hit a pedestrian if he crosses the road and is not seen by the driver. The same applies in the autonomous transport sector, where safety must be at the highest possible level.

Another Bottleneck identified is the need for *high bandwidth* for smart applications in particular in the autonomous transport sector. Even in this case, the future needs for high bandwidth will not be meet by 4G technology.

Companies and organizations interviewed by the researcher are all averagely satisfied with today's use of ICTs to develop smart projects and deliver smart solutions. However, it has emerged that when these projects and smart solutions will be implemented and taken to the next stage, bottlenecks related to the use of ICTs in both the mobile technology and smart solution domains will emerge. The bottlenecks related to the mobile connectivity domain will be **data capacity**, **coverage** and **sensors**. The bottlenecks related to the domain of

smart solutions will be **data generation and data processing**, **low latency and fast response**, **security** and **bandwidth**. It is therefore legitimate, when we refer to these bottlenecks, to talk about *Future Bottlenecks*.

## 6.3 Second Sub-Research Question

As mentioned in paragraph 6.1 and in paragraph 1.5 of the introduction one of the sub research questions to be answered in order to respond to the main research question is:

*To what extent can these bottlenecks be solved through 5G?*

After answering the question about the identification of possible bottlenecks in the utilization of ICTs for delivering smart solutions, the researcher will answer the question about the ability of 5G technology to solve these bottlenecks. The analysis carried out has shown how 5G technology will be able to solve future bottlenecks that are found in the use of ICTs in the mobile technology domain and in the smart solutions domain.

With regard to future bottlenecks that will be found in mobile technology, 5G will help to **solve** the problems related to **data capacity**, **coverage**, and **sensors**.

Regarding the future bottleneck of data capacity, 5G technology will allow a substantial increase in the volume of data generated through the mobile connection thanks to a substantial increase in the data rate, which is the amount of data that a given network can support. In particular, the data rate of 5G is 10^3 times higher than that of 4G technology (Andrews et al., 2014).

Regarding the future bottleneck of coverage, 5G technology will also have a positive impact on this type of criticality. Thanks to 5G technology, there will be a substantial improvement in coverage. In particular, 5G will support the signal at both low and high frequencies, solve indoor coverage problems and allow mobile coverage both inside and outside the city.

Also, the future bottleneck of sensors, will be solved thanks to the contribution of 5G technology, in particular the new generation of mobile connectivity will allow to reduce the cost of sensors in general and to install a greater number of sensors within a restricted area.

As for the future bottlenecks that will be found in the use of ICTs for the future implementation of smart solutions, 5G technology will be able to solve the problems related to **data generation & data processing**, **low latency & fast response**, **security** and **bandwidth**.

As for data generation and data processing, 5G will be a data generation enabler. In particular, thanks to the data rate characteristics of this technology it will be possible to generate more data for the benefit of the sectors that will need it. In particular in the smart building sector, the 5G technology will be able to guarantee a large volume of data generated and processed, and this will allow to collect more data on the habits of smart infrastructure inhabitants in order to make smart buildings more adaptable to the habits of tenants. Similarly, in the healthcare sector, the increased amount of data generated and processed by 5G technology will ensure that more information can be obtained to monitor patient health.

As for the future bottleneck of low latency and fast response, 5G technology will provide the necessary latency for all those smart solutions that need a critical and immediate response. In particular in the smart building sector, the 5G technology will increase the signal speed in buildings and will allow the realization of all those applications that need a low latency and a precise response. In the smart mobility sector, 5G, thanks to its low latency, will make it possible to develop applications related to the world of self-driving vehicles. In the smart energy sector, it will allow a faster and more immediate response within the smart grid. In the smart healthcare sector, 5G will make possible all those applications that need a real-time and precise response, such as remote surgery or remote monitoring. Moreover, the low latency typical of 5G will allow the development of applications in the field of augmented reality and the Internet of Things.

5G will also have a positive impact on the resolution of future security bottlenecks. In particular, thanks to 5G technology we will see an increase in the level of security in smart buildings, making our homes safer. In the area of smart mobility, the reliability of vehicles will be improved. Self-driving vehicles will not only perform better, they will also be safer on the roads. In the smart energy sector, 5G will improve the safety level of the smart grid. In fact, in case of malfunctioning problems within the grid, thanks to the fast response guaranteed by 5G technology, it will be possible to stop the energy plants in case of need and improve the Smart Maintenance.

5G technology will also solve the bandwidth problem. In fact, it will guarantee a high bandwidth service both for smart mobility, smart buildings and virtual and augmented reality.

Although it has emerged that in the future 5G technology will be able to solve future bottlenecks resulting from the use of ICTs to develop smart solutions, the research has shown that there are limiting factors for the establishment of this technology. In particular, it was found that today there is a lack of infrastructure for the

introduction of 5G, a lack of adequate network development and the presence of routers, terminals and devices that are not adequate to support this technology. In addition, it was found that 5G technology is now expensive and only if the price of 5G solutions falls, companies and organizations interested in the development of smart solutions will decide to adopt it. It has also emerged that the current historical moment is not ready for the development of 5G technology and that it will take a long time before the current projects and smart solutions are implemented. That said, it can be said that the **lack of infrastructure**, the **cost issue** and **time issue** are elements that need to be considered in order to discuss how 5G technology will impact the resolution of bottlenecks.

In order to summarize the content of the answer to this question it is possible to state how 5G technology will be able to solve both the future bottlenecks in the mobile technology domain and in the smart solutions domain that have been listed above. In order to do this, however, it is necessary that an adequate infrastructure is developed, that there is an advantageous cost/efficiency ratio and that the historical time is favorable.

## 6.4 Main Research Question

Thanks to the answers obtained to the two sub research questions it is possible to respond to the main research question:

*What bottlenecks in the smart city ecosystem, if any, can be overcome with 5G technology?*

To answer the main research question, the researcher decided to make use of the results obtained from the answers to the two previous sub research questions.
The research carried out showed how 5G technology will be able to solve *future bottlenecks*. Such bottlenecks will in fact only occur in the future when companies and organizations, that are currently satisfied with the actual performance of ICT tools for delivering smart solutions, will need higher levels of performance to improve the implementation of their smart solutions and to scale up the actual smart projects.
Therefore, the *future bottlenecks* that have been identified belong to two different domains: mobile technology and smart solutions. The Bottlenecks related to the world of mobile technology are **data capacity**, **coverage** and **sensors**. The Bottlenecks related to the smart solutions domain are **data generation & data processing**, **low latency & fast response**, **security** and **bandwidth**.

5G technology will solve all the bottlenecks that have been listed because thanks to its structural features it can provide a higher number of generated and processed data, lower latency and faster response, higher security levels and higher bandwidth.

However, in order for the 5G technology to solve future bottlenecks, it is necessary to take into account how fundamental are the development of an adequate support at the infrastructure level, a considerable cost reduction of 5G and a mature historical moment inclined to accept all the benefits brought by this technology. If this does not happen, the bottlenecks that have been identified are unlikely to be resolved.

## 6.5 Future Research Proposals

The Research has shown that in the future there will be bottlenecks related to the use of ICTs that 5G will be able to solve only if the limitations in terms of infrastructure, network, costs and time are resolved. Once these restrictions towards the establishment of 5G are overcome, 5G could establish itself as one of the standard technologies of the market.

In particular when this will happen, it would be interesting to study what are the barriers and facilitators to the use of 5G technology within Swedish companies and organizations. Moreover, this study could be linked to the concept of S-Curves technology and peace of technology substitution (Adner & Kapoor, 2016). In fact, when a technology has assumed a relevant position within a given market, it would be interesting to study if and how a substitution with the previous technology has occurred. Studying if 4G and 5G technology can coexist, or if one will inevitably replace the other could open new research scenarios and very interesting ideas.

Another interesting study that could be carried out concerns the effects of 5G within the business model of the companies or organizations that adopt this technology. In particular through the use of the Business Model Canvas, it would be possible to study the different effects that 5G technology could exert on the different business models of companies that are involved in the development of smart solutions. If instead the focus is on the point of view of companies interested in the commercialization of 5G technology such as Ericsson, it would be of great interest to study in more detail their value proposition through the Value Proposition Canvas tool.

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# Appendixes

## Interview Guide

The researcher used an interview guide consisting of a limited number of questions as he conducted semi-structured interviews so that the respondents' thoughts could flow freely, and the researcher would not influence and prejudge the answers obtained through the interviews. During the interviews the respondents showed several very interesting cues and the researcher in following the conversation formulated a number of collateral questions to the main ones that varied from interview to interview, although all of them had as a common thread the desire to obtain information on the topics of 5G technology, Smart Cities and the application of ecosystem theory to the world of the Smart City.

- Which are the ICTs tools you are actually utilizing in your Company/Organization for businesses implying smart city solutions?

- Are there some projects or collaborations in which you are involved that regard the development of smart solutions?

- Are there some issues you are identifying related to your actual ICT solutions in your projects in order to deliver your value proposition? Could you describe the problems you are facing?

- Do you think these issues can be solved utilizing 5G solutions? If so, are you currently utilizing 5G solutions in your Company/ Organization?

## Table of Coding Process

| Codes | Categories | Aggregate Themes |
|---|---|---|
| Reduction of emissions | Smart Transportation | Smart Solutions |
| Reduction of traffic and vehicle circulation | | |
| Creation of green and sustainable transport | | |
| Creation of green and sustainable logistics | | |
| Trancking of parcels delivered in cities | | |
| Utilization of sensors for bettering the lives of the tenants | Smart Buildings | |
| Increasing the level of security inside the buildings | | |
| Increasing the level of automation inside the buildings | | |
| Bettering the light management system | | |
| Less energy consumption and environmental impact of smart infrastructures | | |
| Ability to adapt to the abits of the tenants | | |
| Improvement of the delivery service for the building inhabitants | | |
| Importance of urban development managment | | |
| Continuos comminication between the infrastructure and the citizen | | |
| Improvement of connectivity in autonomous public transport | Smart Mobility | |
| Autonomous driving capabilities for remote control vehicles | | |
| Strong engament in mobility as a service and car sharing | | |
| Smart routing for public transport, taxis, scooters and rental bikes | | |
| Electrification of urban transport for implementing traffic management | | |
| Smart metering for achieving efficient energy consumption | Smart Energy | |
| Sensors and connectivity in the grid for providing more information | | |
| More information processing for renewable energies | | |
| District heating will be affected by smart solutions in the energy grid | | |
| Remote operations carried out with the remote control of machines | Smart Healthcare | |
| Digitalization of healthcare | | |
| Introduction of sustainable waste disposal systems | Smart waste | |
| Digitalization of waste collection | | |
| Surveillance and security of smart buildings | Smart Security | |
| Improving security in the city thanks to remote vehicle control | | |
| Implementation of security systems within the smart grid | | |

| | | |
|---|---|---|
| Development of drone-based surveillance system | | |
| 3G technology utilized for creating smart city solutions | Mobile technology and Smart Solutions | ICT tools for delivering smart solutions |
| 4G technology utilized for creating smart city solutions | | |
| IoT applications are central for developing smart solutions | IoT applications | |
| Utilization of sensors for data collection and data monitoring | Sensors | |
| LoRa (Long Rage) modulation meets the demand for cost efficiency | LoRA for cost efficiency | |
| Wi-Fi adoption by non tech companies | Wi-fi adoption | |
| Standalone 5G utilization for developing smart solutions | 5G utilization nowadays | |
| Non-standalone 5G utilization for developing smart solutions | | |
| Adoption of Edge Computing for developing smart solutions | Edge Computing, Artificial Intelligence and Machine Learning | |
| Adoption of Artificial intelligence for developing smart solutions | | |
| Adoption of Machine Learning for developing smart solutions | | |
| Adoption of VPN technology | VPN | |
| Adoprion of "Scada" system | "Scada" | |
| Adoption of "Zigbee" system | "Zigbee" | |
| Current Satisfaction wirth actual 4G performance | 4G actual satisfactory performance | Mobile technology future bottlenecks |
| 4G technology is sufficient for ordinary communication | | |
| 4G will not meet the future performance demands | Data capacity future bottleneck | |
| 4G will lack enough data capacity in the future | | |
| 4G Lack of processing smart devices future data capacity | | |
| 4G coverage problems inside and outside cities | Coverage bottleneck | |
| The use of sensors is limited and expensive | Sensors bottleneck | |
| Sensor problem for connectivity away from repeaters | | |
| Sensors high concentrated in small areas lack of performance | | |
| 4G is actually suffient for Smart Transportation | Smart Transportation well performing now | Smart Solutions Actual Performance with ICTs |
| 4G is actually sufficient for tracking parcels | | |
| Current technology is actually sufficient for Smart Buildings | Smart Building well performing now | |
| Satisfaction with actual terchnologies for Smart Building projects | | |
| Current technologies are sufficient for smart mobility | Smart Mobility well performing now | |
| 4G is suffient for for basic vehicle automation | | |
| Satisfaction with 4G perfomance in Smart Energy | Smart Energy well performing now | |
| Fiber,4G, wi-fi sufficient for Smart Grid solutions | | |
| 4G will not provide sufficient data volume | | |
| 4G will not provide enough data processing in the future | | |

| | | |
|---|---|---|
| 4G not sufficient for data driven heathcare | Data Generation & Data Processing Bottlneck | Future ICT bottlenecks in Smart Solutions |
| 4G will not guarantee enough data processed for smart heatlthcare | | |
| 4G will not be enough for tracking parcels in the future | | |
| 4G will not provide enough data processing in vehicles | | |
| Smart transportation future speed demand is not meet by 4G | Low Latency & Fast Response Bottleneck | |
| 4G will not provide adequate low latency for Smart Buildings | | |
| 4G will not provide fast response for Smart Buildings | | |
| 4G will not bring enough low latency for Smart Mobility | | |
| 4G lacks low latency for autonomous transport | | |
| 4G can't offer real time response in heathcare | | |
| 4G can't offer critical response in healthcare | | |
| 4G lacks reliability for autonomous transport | Security Bottleneck | |
| 4G will not provide enough security | | |
| 4G will not ensure enough safety for Smart Mobility | | |
| 4G lacks security for autonomous transport | | |
| 4G lacks high badwidth for autonomous transport | Bandwidth Bottleneck | |
| 5G will better data capacity | 5G solving data capacity bottleneck | 5G solving mobile technology future bottlenecks |
| 5G will increase the volume of data generated and processed | | |
| 5G will improve coverage | 5G solving coverage bottleneck | |
| 5G will support high frequencies | | |
| 5G will solve indoor coverage problems | | |
| 5G will solve coverage problems inside and outside cities | | |
| 5G will support low frequencies | | |
| 5G will reduce the cost of sensors | 5G solving sensors bottleneck | |
| 5G will lead to increasing the number of sensors | | |
| 5G will enable more data generation | 5G solving Data Generation & Data Processing | |
| 5G will bring high capacity for for Smart Buildings | | |
| 5G will provide a large amount of data to the healthcare sector | | |
| 5G will increment the speed of signal in buildings | 5G solving Low Latency & Fast Response Bottleneck | |
| 5G will bring low latency for smart buildings | | |
| 5G will bring fast response for Smart Buildings | | |
| 5G will guarante low latency for self driving vehicles | | |
| 5G will provide low latency to the grid | | |
| 5G will provide quick response to the grid | | |

| | | |
|---|---|---|
| 5G low latency impact on remote surgery and monitoring | | 5G solving future ICT bottlenecks in Smart Solutions |
| 5G will provide fast and immediate response in smart healthcare | | |
| 5G will provide low latency for AR | | |
| 5G will provide low latency and low spectrum for IoT applications | | |
| 5G will better security of buildings | 5G solving security Bottleneck | |
| 5G will better the surveillance of buildings | | |
| 5G will provide reliability for Smart Mobility | | |
| 5G will solve criticalities in the grid | | |
| 5G will improve security in the grid | | |
| 5G will improve efficiency for smart maitainance | | |
| 5G will bring high bandwidth for Smart Buildings | 5G solving bandwidth Bottleneck | |
| 5G will provide high bandwidth for Smart Mobility | | |
| 5G will provide bandwidth for AR and VR | | |
| Lack of infrastructure for 5G implementation | Lack of infrastructure fot 5G | Limits towards 5G implementation |
| Lack of 5G network | | |
| Routers, terminals and devices are not adequate for 5G | | |
| 5G is too costly | 5G cost issue | |
| Hystorical moment is not mature for 5G | 5G time issue | |
| Delaying on 5G future benefits for smart projects | | |
| Long time before scaling up 5G solutions | | |

UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

**Master Thesis Double Degree Program**

**in Innovation and Industrial Management**

# Smart Cities as Ecosystems

What Will be the Impact of 5G?


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# MASTER THESIS SUMMARY

## INTRODUCTION:

### Project Outline

This Master Thesis project was born thanks to the collaboration between the researcher and the Swedish consultancy firm FIRST TO KNOW (FTK) located in Gothenburg, Sweden. The aim of FTK is to enable organizations to reach their maximum potential and to bridge the gap between business and academia in order to facilitate the innovation process in which many companies are involved. The support of FTK allowed the researcher to focus on a topic of its interest and that could match the vision of the Swedish firm at the same time. Since the researcher participated in the Double Degree program between the University of Göteborg and Luiss Guido Carli in Rome, the contribution of the Italian relator was of fundamental importance in order to realize a valid work that could contribute from an academic point of view.

### Background

The background on which this thesis is based origins from the concept of smart city seen as a business ecosystem and from the trials for the utilization of 5G technology in cities that have been carried out in the recent years. There is evidence that the smart city can be considered as a business ecosystem rather than a marketplace. According to Alusi et al., (2011, p. 12) a smart city can be defined as "an ecosystem of large and small company partners that will focus on creating products and services for sustainable urbanization". As claimed by Díaz-Díaz et al., (2017) a smart city is defined as an ecosystem composed of different stakeholders from the public and the private sector that collaborate together in order to make cities intelligent and sustainable. Another fundamental aspect concerning the background of the research project are the trials that have been launched with the development of 5G technology within cities in order to make the urban ecosystem services smarter and more efficient. Two examples are the cities of Prato and L'Aquila, which have been test fields for 5G. In these cities 5G was implemented in order to test the impact this technology could have on various smart solutions such as: e-health, smart grid, IoT and smart sensors, city surveillance, smart safety, smart mobility, augmented reality, virtual reality and structure monitoring for buildings (Marabissi et al., 2019).

### Research Problem

Smart cities are often defined in literature as a business ecosystem and trials have been conducted to apply 5G technology for implementing smart solutions in cities across the word. However, it has emerged that there are no studies in which business ecosystem theory is applied to smart cities and in particular to the study of the

effect that 5G technology may have on smart solutions (the components of this unique business ecosystem). Therefore, the researcher identified this reasoning path as the research problem.

### Research Purpose

In order to fill this gap, the researcher decided to apply business ecosystem theory to smart cities and in particular to study the effects of 5G technology on smart solutions.
To do this, the theoretical notions of business ecosystem theory, resulting from the work of Adner and Kapoor, were utilized. In particular, the researcher based his study on the concept of bottleneck, a fundamental element of business ecosystem theory. A bottleneck is a component (or value offer) of an actor participating in a business ecosystem, which, due to its performance gaps, worsens the performance of the entire business ecosystem. Therefore, the research purpose is to focus on the identification of possible bottlenecks in the use of current ICTs (information and communication technologies) to implement smart solutions, and on the possibility of 5G to solve such bottlenecks.

### Research Question

Taking into account the background, the discussion of the problem and the purpose of the study, the research question can be formulated as follows:

*What bottlenecks in the smart city ecosystem, if any, can be overcome with 5G technology?*

In order to answer the question, the researcher had to break down the main research question in two sub-questions:

*Which are the bottlenecks of the ICT tools for delivering smart solutions?*

*To what extent can these bottlenecks be solved through 5G?*

## LITERATURE REVIEW

The literature review (coinciding with the secondary data collection) is the theoretical foundation of the research project. In particular, this section of the thesis is divided into three parts: one related to 5G technology, one related to business ecosystem theory, and one related to the smart city.

## 5G

Thanks to 5G technology the amount of data that a network can support will increase by 10^3 times compared to the current 4G network. Latency, the time interval between the data stimulation and the data response, will be reduced and 5G will support all the applications that require an immediate reaction like automated industrial production, robotics, transportation, healthcare, entertainment and virtual reality. Moreover, 5G will consume less energy and will require lower costs than the previous mobile technology generations (Andrews et al., 2014). 5G will also have strong relationships with the industrial world, in fact there are many industries in which 5G technology will play a crucial role in connecting people and objects. Among these industries there are healthcare, manufacturing, entertainment, automotive, energy, public transport, agriculture, public safety, megacities and smart cities. In addition to the different industrial sectors where 5G technology will have a strong impact, it is possible to identify some use cases where 5G technology will play a key role in the near future. These use cases belong to certain general domains like: Massive IoT, Time Critical Communication, Mobile Connectivity, Vehicular Communication and Network Operations (Chandramouli et al., 2019).

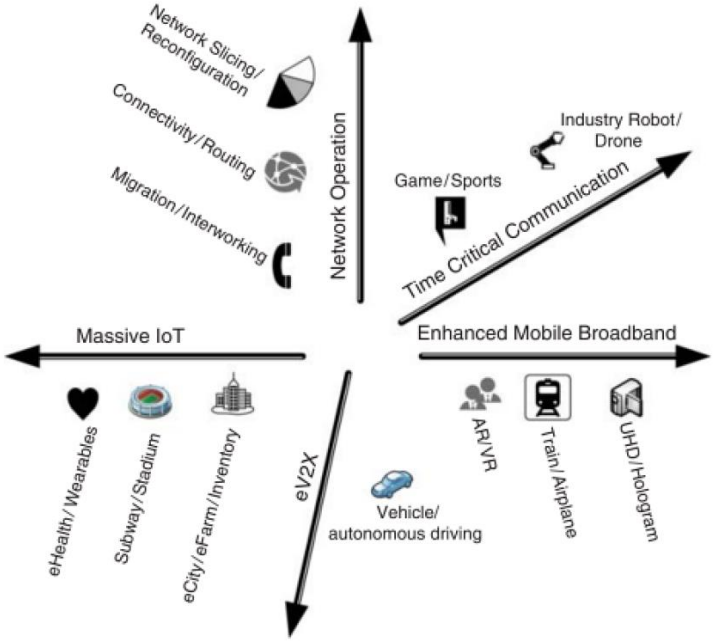


Fig.1: 5G use case categories. *Source: Chandramouli et al., 2019, p.10*

## Business Ecosystem Theory

A business ecosystem consists of a a set of firms and organizations from different industries that collaborate in the creation of a value proposition for the end customer. The elements that make up a business ecosystem take precise names within business ecosystem theory. *Actors* are the companies participating in the ecosystem. These include the *focal firm* and the *complementors*. The *focal firm* exercises the role of leader within the ecosystem and plays a central function in terms of creation of the final value offer (Moore, 1993).

*Complementors* are all other companies that contribute to the realization of the final value offer. In this case more than the focal firm, the researcher decided to focus on the final value offer for the consumer, which consists on the smart city. The actions that are carried out by the various companies involved in the business ecosystem for delivering the final value proposition are called *activities*. Among the *activities* is possible to distinguish two different main concepts: the concept of *component* and the concept of *bottleneck*. *Components* constitute the contributions in terms of goods or services that the complementors realize for delivering the final value proposition. If a component turns out to be poorly performing and blocks the entire realization of the final value offer, it takes the name of *bottleneck.*

Two different strategies can be adopted to study business ecosystems. One, called *ecosystem strategy* focuses on the stability or not of the relationships that are created between the actors of the ecosystem. The ecosystem strategy is characterized by the focus on the *alignment of partners*, which is studied thanks to the *ecosystem mapping.* Through the ecosystem mapping is possible to find the causes of delays in the value offer delivery of a business ecosystem.

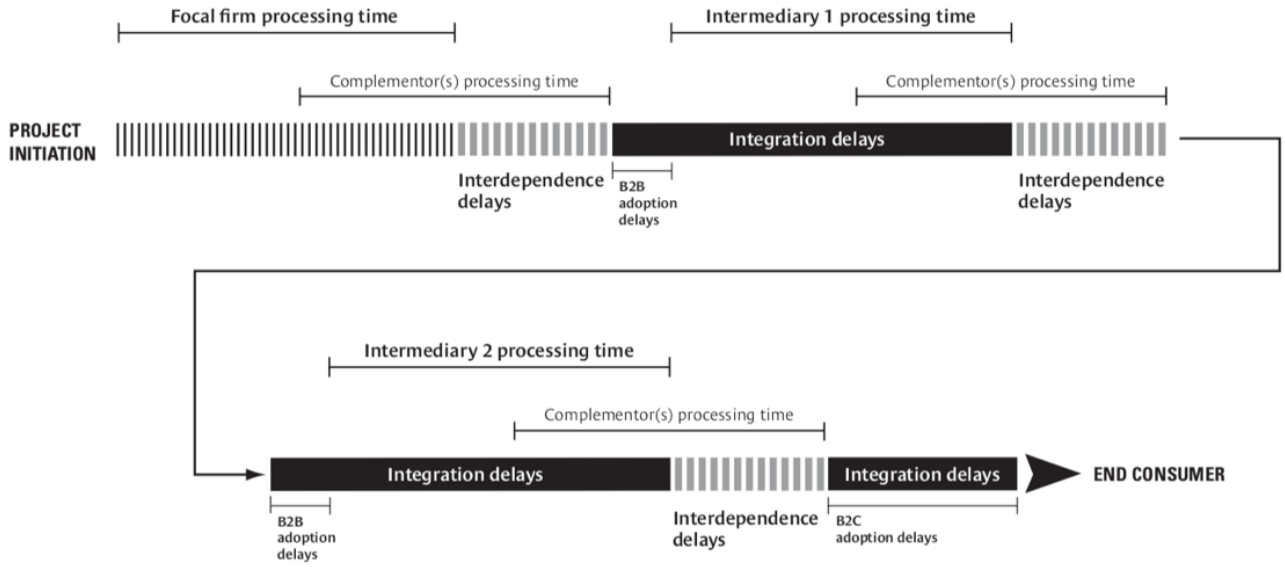


Fig.2: Mapping the Ecosystem. *Source: Adner, 2006, p.7*

The other, called *bottleneck strategy* focuses on identifying and overcoming components that have insufficient performance (bottlenecks). For spotting a bottleneck inside a business ecosystem it is necessary to study a particular component and if the ecosystem fails to perform in a good way because of that component, a bottleneck is faced (Baldwin, 2015). This strategy foresees a reciprocal relationship between cooperation and competition between the partners of an ecosystem: when a business ecosystem actor succeeds in unlocking a bottleneck, he must be able to create and capture value. Companies that want to create value through technology have the necessary need to search and solve bottlenecks.

### Smart Cities

Although the definition of the concept of smart city is still vague, it is possible to identify the smart city as an ecosystem devoted to innovation, entrepreneurship and creativity that bases its implementation on an information technology network (Anttiroiko et al., 2014). A smart city can be defined as an ecosystem in which we see the presence of different technologies connected to each other in such a way as to guarantee an improvement in the functions performed in a city. An ecosystem of this type requires the presence of different stakeholders who must collaborate with each other (Abu-Matar, 2016). Couzineau-Zegwaard et al., (2013) highlighted in their study that is possible to compare the concept of smart city with that of business ecosystem. Just as business ecosystems are composed of different components (i.e. individual value offers that contribute to the realization of a final value offer), smart cities are similarly composed of different components. These include the value offers of smart transportation, smart mobility, smart healthcare, smart energy and smart buildings. Integrating smart transportation systems within the city would improve public transport service, reduce costs and increase security (Silva et al., 2018). One of the main applications of smart mobility are autonomous vehicles. An autonomous vehicle, thanks to the use of technologies that implement its connectivity and sensors that capture data, increases road safety, improves traffic flow and reduces energy consumption. One of the most relevant applications of smart healthcare is remote health monitoring, which can be used to visit non-critical patients remotely, thus reducing the number of doctors in the hospital (Baker et al., 2017). Smart energy will aim at reducing the gap between renewable and non-renewable energy sources.

## METHODOLOGY

### Research Strategy

Since the purpose of the research is to investigate whether bottlenecks exist in the smart city as a business ecosystem and whether they can be solved through the use of 5G technology, the use of a *qualitative* research strategy seems to be the most suitable for the purpose. Qualitative research is characterized by the fact that it emphasizes words rather than numbers and quantification of data. Qualitative research in fact allows the researcher to obtain opinions, points of view and reflections of respondents regarding a specific topic.

### Research Design

According to Bryman and Bell (2011) the case study research design allows a detailed and specific analysis of an event, person or entity that is the subject of the research work. In particular when we refer to the term case, it is associated to a system or entity with a precise purpose and defined functioning parts. Another

characteristic element of the case study is that the phenomenon studied must be limited to a specific geographical area of interest.

For this reason, the researcher thought that this type of research design was the most appropriate for the development of his master thesis on smart cities as a business ecosystem.

The smart city consists of an entity or a system composed of several functioning parts called smart solutions. Through their contribution in terms of value offer, they allow the realization of the purpose of the smart city: the improvement of the living conditions of the citizens. In addition, the research was carried out entirely in Sweden and more specifically in the city of Gothenburg, where the researcher collected all the information needed to carry out his work.

## Research Methods

Data needed to respond to the research questions of this study come from two different sources: primary data and secondary data. Primary data collection consists in a process of gathering first-hand data by the researcher. These data come from the opinions, ideas, perceptions and scientific evidence arising from the interview process, which is the most common way to collect primary data in qualitative research (Bryman & Bell, 2011). To carry out this research, the method of semi structured interviews was used. In fact, they allow the respondents to space and share their opinions and thoughts with the researcher, but at the same time they narrow the focus of the research. At the practical level, the secondary data collection (literature review) was carried out looking for information about 5G technology, smart cities and business ecosystems. Information was collected through academic papers, books, scientific and academic journals which were found from online resources. In particular, Google Scholar, the University of Gothenburg Library and the Luiss Library were used.

## Selection of cases

The selection of respondents or sampling is a fundamental element within a thesis work, because through it the researcher chooses which group of people to draw from in order to carry out his primary data collection. Within this research a mix between purposive sampling and snowball sampling was used. First of all, companies and organizations respondents belonging to the categories of those who had experience in the world of 5G, ICTs, smart cities, smart projects and smart cities solutions were chosen leveraging on FTK network and thanks to the utilization of the purposive sampling. During the course of the primary data collection, other respondents were added to the original number thanks to the snowball sampling. That is, some of the respondents, at the request of the researcher, provided contacts in order to include other respondents in the research project. In particular it was possible to select respondents from different companies and organizations such as: IBM, Tele2, Atea, Ericsson, Telia, Göteborg Energi, Lindholmen Science Park and the City of Göteborg.

### Data Analysis

Data which had been collected thanks to the interview process were analysed thanks to the thematic analysis. The process of thematic analysis makes use of different phases, which are necessary in order to study the information obtained. The first phase of thematic analysis consists in the creation of the “codes” or “first order concepts” and is called "coding phase". The second step is the comparison process. During this phase the so-called "categories" emerge. The categories are the result of the comparison of the various codes and the agglomeration of those with similarities in terms of meaning. Once the categories have been elaborated, the researcher proceeds with their aggregation and the establishment of the "aggregate themes". A theme is an agglomeration of two or more categories, which can be used to answer our research question. During the data analysis the researcher considered fundamental not only to organize the data obtained in the primary data collection through the coding process, but also to compare them with the data obtained in the secondary data collection. In this way it was possible to highlight possible matches and discrepancies between the two types of data that were collected by the researcher.

## EMPIRICAL FINDINGS AND DATA ANALYSIS

Through the thematic analysis it has emerged how 5G, thanks to its features, is able to solve future bottlenecks that will arise in the domain of mobile technology in the areas of *Data Capacity*, *Coverage* and *Sensors*.
5G will bring many benefits compared to 4G technology in particular with regard to the amount of data that can be processed. By comparing the data obtained through the interviews the researcher observed that 5G technology will have an important effect on the increase in data capacity, which was one of the main shortcomings of 4G technology. It also emerged how 5G will have a significant impact on coverage since it will support both low and high frequencies and it will solve coverage problems inside and outside cities. 5G will also have an impact on sensor technology. In fact, thanks to this innovation, the cost of sensors will be reduced, and the number of sensors concentrated in a small area will be augmented in order to process more data. Another finding that emerged is that 5G will be able to solve future bottlenecks that will occur in the ICTs in order to bring to the next stage some of the current smart solutions. It emerged how, thanks to the features of 5G technology, it will be possible to solve the bottlenecks of *Low latency & Fast response*, *Data generation* & *Data processing*, *Security* and *Bandwidth*. Through the thematic analysis it has emerged how there are some limits towards the implementation of 5G technology. In particular, it emerged that the 5G technology and consequently its applications have not yet reached a mature development due to the lack of an adequate infrastructure to support them. In particular, there is not a network adequately implemented at national (Sweden) and international level that can allow the development of 5G technology in several countries at the same time. There are also shortcomings in terms of devices, routers and terminals with adequate performance. Another issue that could slow down the development of 5G technology is the cost. In fact, although many of the companies interviewed believe that 5G technology can bring substantial improvements

in their smart solutions, they are also aware that if the price of 5G is too high, they will hardly decide to adopt this technology. Another problem that can slow down the application of 5G technology is that of time. In particular, it emerged how we are in a historical moment not yet mature and ready to adopt 5G technology solutions. In fact, according to many of the companies interviewed, even if they decided to adopt 5G solutions, the results of these applications would be obtained in a period that in some cases is around two years, while in other cases it can reach up to eight years.

| Future Bottlenecks in Mobile Technology |
|---|
| Data Capacity |
| Coverage |
| Sensors |

Tab.1: Future Bottlenecks Identified in Mobile Technology. *Source: Author*

| Smart Solutions Actual Performance with ICTs and Future ICT Bottlenecks |
|---|
| Low Latency & Fast Response |
| Safety |
| Data Generation & Data Processing |
| Bandwidth |

Tab.2: Future Bottlenecks solved thanks to 5G. *Source: Author*

| Future Bottleneck | 5G Solved |
|---|---|
| Data Capacity | yes |
| Coverage | yes |
| Sensors | yes |
| Low Latency & Fast Response | yes |
| Safety | yes |
| Data Generation & Data Processing | yes |
| Bandwidth | yes |

Tab.3: Future Bottlenecks solved thanks to 5G. *Source: Author*

| Limits Towards 5G implementation |
|---|
| Infrastructure |
| Cost |
| Time |

Tab.4: Limits towards 5G Implementation. *Source: Author*

# CONCLUSIONS

As explained in the introduction, the researcher developed a main research question: *What bottlenecks in the smart city ecosystem, if any, can be overcome with 5G technology?* and two sub research questions which are respectively: *Which are the bottlenecks of the ICT tools for delivering smart solutions?* and *To what extent can these bottlenecks be solved through 5G?*. In order to answer the main research question, the researcher decided to address first the two sub-research questions and then the main research question.

## First Sub Research Question

The fist sub-research question that has been addressed is:

*Which are the bottlenecks of the ICT tools for delivering smart solutions?*

Companies and organizations interviewed by the researcher are all averagely satisfied with today's use of ICTs to develop smart projects and deliver smart solutions. However, it has emerged that when these projects and smart solutions will be implemented and taken to the next stage, bottlenecks related to the use of ICTs in both the mobile technology and smart solution domains will emerge. It is therefore legitimate, when we refer to these bottlenecks, to talk about *Future Bottlenecks*.

In the domain of mobile connectivity three main bottlenecks will emerge **data capacity**, **coverage** and **sensors**. It has emerged that current technologies, and in particular 4G technology in the future, will not be able to provide sufficient data capacity when demand for data will rise due to the increase in the number of connected devices. In the same way 4G technology will experience performance problems related to the coverage needed both inside and outside the cities. In particular, when it will be necessary to bring connectivity to areas outside the city centre, such as the countryside, 4G will not be able to provide the necessary level of coverage required.
Another criticality will be found in sensors. In fact, when it will be necessary to increase their number and concentration in small areas, the current use of 4G technology will not guarantee satisfactory levels of performance. Moreover, due to the lack of adequate connection capacity of the sensors far from the repeaters, their installation in places far from the connection sources will not be possible with the current ICTs. At the moment the only way to install sensors in new areas is to install a new repeater and this is expensive.

In the domain of smart solutions, the ICT bottlenecks that will emerge in the future will be multiple. The researcher identified four main bottlenecks that will be found when smart solutions are implemented and current smart projects are scaled up: **data generation & data processing**, **low latency & fast response**, **security** and **bandwidth**.

In smart transportation, smart healthcare and smart mobility, 4G technology will not be able to support future demand for *processed and generated data*. Especially in smart transportation, when more data production and processing will be needed to track objects, 4G technology will not provide the required support. In smart healthcare the demand for data collected and processed to obtain patient information will not be matched by the current performance of 4G technology. In smart mobility, when vehicles will need to collect and process more data than current 4G technology, actual 4G technology will lack performance.

*Low Latency*, i.e. the low delay between the generation and process of an input, is one of the fundamental requirements of all those smart solutions that need a *fast response* to perform their task in situations that require criticality and immediacy. Through the analysis carried out it emerged that in the future, when smart solutions will be implemented and brought to the next stages the low latency required will not be supported by current technologies and in particular by 4G technology. In the smart healthcare sector, the current 4G technology will not be able to provide the necessary real-time response for the applications concerning remote surgery and remote monitoring of people. Likewise, in the smart building sector, 4G technology will not be able to provide the low latency and immediate response necessary for all those applications concerning surveillance and security within smart infrastructures. In the smart mobility sector, current ICTs and 4G technology will constitute a future bottleneck because they will not meet future requirements in terms of low latency and critical response. All the applications concerning self-driving vehicles will not be realized without being able to benefit from an immediate and real-time response. Likewise, in the smart transportation sector, 4G technology will not be able to support future demand for speed and low latency, as for example in the autonomous transport applications.

## Second Sub Research Question

The second sub-research question to be addressed is:

*To what extent can these bottlenecks be solved through 5G?*

The analysis carried out has shown how 5G technology will be able to solve future bottlenecks that are found in the use of ICTs in the mobile technology domain and in the smart solutions domain.

With regard to future bottlenecks that will be found in mobile technology, 5G will help to **solve** the problems related to **data capacity**, **coverage**, and **sensors**.

Regarding the future bottleneck of data capacity, 5G technology will allow a substantial increase in the volume of data generated through the mobile connection thanks to a substantial increase in the data rate, which is the amount of data that a given network can support. In particular, the data rate of 5G is 10^3 times higher than that of 4G technology (Andrews et al., 2014).

Regarding the future bottleneck of coverage, 5G technology will also have a positive impact on this type of criticality. Thanks to 5G technology, there will be a substantial improvement in coverage. In particular, 5G will support the signal at both low and high frequencies, solve indoor coverage problems and allow mobile coverage both inside and outside the city.
Also, the future bottleneck of sensors, will be solved thanks to the contribution of 5G technology, in particular the new generation of mobile connectivity will allow to reduce the cost of sensors in general and to install a greater number of sensors within a restricted area.

As for the future bottlenecks that will be found in the use of ICTs for the future implementation of smart solutions, 5G technology will be able to solve the problems related to **data generation & data processing**, **low latency & fast response**, **security** and **bandwidth**.

As for data generation and data processing, 5G will be a data generation enabler. In particular, thanks to the data rate characteristics of this technology it will be possible to generate more data for the benefit of the sectors that will need it. In particular in the smart building sector, the 5G technology will be able to guarantee a large volume of data generated and processed, and this will allow to collect more data on the habits of smart infrastructure inhabitants in order to make smart buildings more adaptable to the habits of tenants. Similarly, in the healthcare sector, the increased amount of data generated and processed by 5G technology will ensure that more information can be obtained to monitor patient health.
As for the future bottleneck of low latency and fast response, 5G technology will provide the necessary latency for all those smart solutions that need a critical and immediate response. In particular in the smart building sector, 5G technology will increase the signal speed in buildings and will allow the realization of all those applications that need a low latency and a precise response. In the smart mobility sector, 5G, thanks to its low latency, will make it possible to develop applications related to the world of self-driving vehicles. In the smart energy sector, it will allow a faster and more immediate response within the smart grid. In the smart healthcare sector, 5G will make possible all those applications that need a real-time and precise response, such as remote surgery or remote monitoring. Moreover, the low latency typical of 5G will allow the development of applications in the field of augmented reality and the Internet of Things.
5G will also have a positive impact on the resolution of future security bottlenecks. In particular, thanks to 5G technology we will see an increase in the level of security in smart buildings, making our homes safer. In the area of smart mobility, the reliability of vehicles will be improved. Self-driving vehicles will not only perform better, they will also be safer on the roads. In the smart energy sector, 5G will improve the safety level of the smart grid. In fact, in case of malfunctioning problems within the grid, thanks to the fast response guaranteed by 5G technology, it will be possible to stop the energy plants in case of need and improve the Smart Maintenance.

5G technology will also solve the bandwidth problem. In fact, it will guarantee a high bandwidth service both for smart mobility, smart buildings and virtual and augmented reality.

Although it has emerged that in the future 5G technology will be able to solve future bottlenecks resulting from the use of ICTs to develop smart solutions, the research has shown that there are limiting factors for the establishment of this technology. In particular, it was found that today there is a lack of infrastructure for the introduction of 5G, a lack of adequate network development and the presence of routers, terminals and devices that are not adequate to support this technology. In addition, it was found that 5G technology is now expensive and only if the price of 5G solutions falls, companies and organizations interested in the development of smart solutions will decide to adopt it. It has also emerged that the current historical moment is not ready for the development of 5G technology and that it will take a long time before the current projects and smart solutions are implemented. That said, it can be stated that the **lack of infrastructure**, the **cost issue** and **time issue** are elements that need to be considered in order to discuss how 5G technology will impact the resolution of bottlenecks.

## Main Research Question

Thanks to the answers obtained to the two sub research questions it is possible to respond to the main research question:

*What bottlenecks in the smart city ecosystem, if any, can be overcome with 5G technology?*

To answer the main research question, the researcher decided to make use of the results obtained from the answers to the two previous sub research questions.
The research carried out showed how 5G technology will be able to solve *future bottlenecks*. Such bottlenecks will in fact only occur in the future when companies and organizations, that are currently satisfied with the actual performance of ICT tools for delivering smart solutions, will need higher levels of performance to improve the implementation of their smart solutions and to scale up the actual smart projects.
Therefore, the *future bottlenecks* that have been identified belong to two different domains: mobile technology and smart solutions. The Bottlenecks related to the world of mobile technology are **data capacity**, **coverage** and **sensors**. The Bottlenecks related to the smart solutions domain are **data generation & data processing**, **low latency & fast response**, **security** and **bandwidth**.
5G technology will solve all the bottlenecks that have been listed because thanks to its structural features it can provide a higher number of generated and processed data, lower latency and faster response, higher security levels and higher bandwidth.
However, in order for the 5G technology to solve future bottlenecks, it is necessary to take into account how fundamental are the development of an adequate support at the infrastructure level, a considerable cost

reduction of 5G and a mature historical moment inclined to accept all the benefits brought by this technology. If this does not happen, the bottlenecks that have been identified are unlikely to be resolved.

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