UNIVERSITY OF TURKU

ABSTRACT

Abstract

This paper aims at showing the link between the fifth-generation mobile network and the concept of smart cities. Herein, the goal is to argue how could Luxembourg evolve towards a smart city with 5G.

5G demonstrates several distinctions compared to its predecessor the fourth-generation, such as its ultra-high reliability and low-latency, its efficiency, capacity as well as its greater coverage. Thanks to those main characteristics, it is an enabler of many new use cases and it could potentially support Luxembourg tackle its main challenges that are mobility, housing, and healthcare. Although this technology seems to present new possible applications and capabilities, it also has drawbacks such as, amongst others, the need to have 5G-enabled devices to use it. Indeed, it does not appear to be the logical continuation of 4G but more of an advanced technology that could disrupt the decade ahead of us. Thereafter, the concept of a smart city is discussed and argued in this research paper, aiming to evaluate the smartness of Luxembourg regarding its public sector, and mostly the sectors representing the biggest defy for the country.

Academic literature has been studied in this research paper and compared with the conducted interviews of both the public sector and 5G. This has also been supported by the conduction of a survey that aimed to evaluate Luxembourg's inhabitants' expectations and needs for the future of their country, and mainly regarding the three challenging sectors as well as their potential fears regarding the implementation of 5G in the Grand-Duchy. Advantages of Luxembourg to both become a smart city and to deploy 5G are discussed and counterbalanced with the challenges the city could face during this evolution towards an increased smartness.

LUXEMBOURG'S EVOLUTION FROM CITY TO SMART CITY WITH 5G

Master's Thesis
in Information Systems Science

Author:
Célia Etard

Supervisors:
Patrick Rousseau,
Timo Leino,
Anne Rutkowski

15.06.2020
Turku

ACKNOWLEDEGMENTS

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1 INTRODUCTION

"Every once in a while, a new technology, an old problem, and a big idea turn into an innovation"

– Dean Kamen

1.1 Background and motivation

1.1.1 Background

As we are entering a new decade, new business trends are emerging such as many tech trends. Drones, improvement in the Internet of Things (IoT), advanced Augmented Reality (AR), and Virtual Reality (VR), quantum computing, and several other technologies could be considered as huge disrupters of this new decade 2020.

Many trends are expected to be disrupting the decade such as the future of the workforce, new emerging technologies, environmental trends with the reduction of carbon footprint, cybersecurity, as well as a greater appeal for innovation (EY, & Mitchell, P., 2019).

In another report, Little, J. (2020) adds data analytics and cloud as other trends expected to be disrupting 2020 and the decennary ahead. While Buchholz, S., Deloitte, & Briggs, B. (2020) sum to that list digital twins, cognitive technologies – machine learning, Robotic Process Automation, neural networks, etc. –, quantum computing and blockchain. Besides, 4D printing seems to be another tech trend of the decade ahead of us (Koot & Soonius, 2018).

But one of the biggest trends that will disrupt existing technologies and our way of living and working is the fifth-generation of wireless communication technology. The deployment of 5G started in early 2019 in South Korea and is little by little being implemented in the whole World. In Europe, 5G starts to be implemented and should be deployed in Luxembourg in 2020 according to the Government of the Grand-Duchy of Luxembourg (2018) (Appendix 1). According to Deloitte. (2018) in its report "Will 5G remake the world", 5G is waited to potentially turn out to be the most revolutionary and the most disrupting progress in mobile communication yet.

5G is seen as an enabler of many use cases and other technologies. One of the use cases 5G enhances is the concept of smart city (Phan & Qureshi, 2017, Marabissi et al, 2018, and Koot & Soonius, 2018).

According to the European Commission (2016), seventy-two percent of EU citizens live in urban areas, and this percentage is expected to increase by up to eighty-four percent by 2050. Therefore, It seems crucial for cities to become smarter to be aligned with businesses' and citizens' needs.

1.1.2 Motivation

All those trends for this new decade explain the motivation figure that has been built (Figure 1). Indeed, we can find in it several streams as emerging trends i.e. new ways of working, new technologies, environmental trends, cybersecurity, innovation, etc.
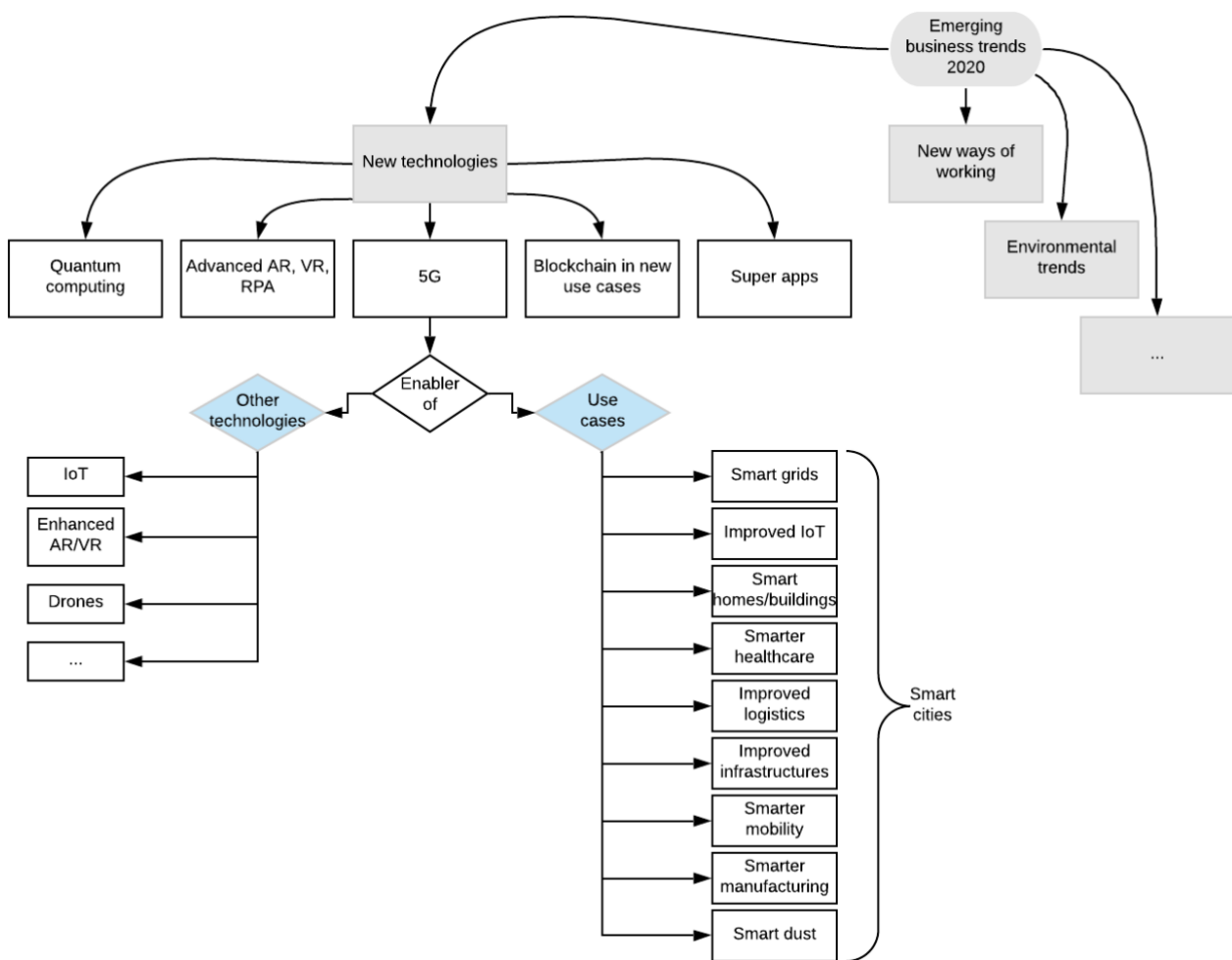
Figure 1. Motivation

The streams "New ways of working" and "Environmental trends" have not been developed for a specific reason: this paper focuses on new technologies, and more especially on 5G. Therefore, the "New technologies" stream has been divided into two main parts: "Enabler of other technologies" in which we can encounter, amongst others,

Augmented Reality, Virtual Reality, Drones, Internet of Things (IoT,), etc., and "Enabler of use cases". This stream will be shortly discussed in Chapter Two. On the latter stream, we can observe that 5G is an enabler of many elements that are included in Smart Cities, which will be discussed in Chapter Two and represents the main motivation of this research thesis.

This motivation leads us to a specific structure of this paper, which will be further presented (Figure 2).

1.2   Main concepts

Two main concepts will be explained and discussed in this paper: 5G technology and the concept of a smart city will be defined.

1.2.1   5G

Wireless mobile communication started its existence with 1G from the 1980s and evolved from 1G (first-generation) to 5G (fifth-generation) in about forty years (Nalin et al., 2019). Wireless mobile communication is a network that is being used since the first mobile phone. The fifth generation of wireless communication technology deployment is slowly progressing throughout Europe. Monaco was the first country of the continent to have 5G in July 2019.

5G is an enabler of several technologies and use cases. As such, smart cities are made more efficient with 5G technology.

The concept of 5G will further be explained in detail in the second Chapter.

1.2.2   Smart cities

The European Commission (2016) defines smart cities as "*a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies, for the benefit of its inhabitants and businesses*".

Moreover, according to this same report from the European Commission, smart cities are supposed to be innovative with the objective of making traditional networks and services more effective thanks to digital technologies. Thus, this would lead to a creation of more "*inclusive, sustainable and connected cities for the benefit of inhabitants, public administrations and businesses*". The overall objective of smart cities would be, in consequence, to ensure the needs of generations for now and for the future, while

overcoming the environmental, economic, and social challenges. It covers several fields such as mobility, governance, and the economy. Some use cases of a smart city are smart waste, smart lighting and, heating of buildings, smart urban transportation, amongst others.

This definition of a smart city will be further discussed and compared with academic literature in Chapter Two.

1.3   Research questions

The main research question this paper aims to answer is the following: "**How could 5G enable Luxembourg to become a smart city?**". This question is epistemological and aims to understand a specific phenomenon. Herein, the objective is to understand the role of 5G in the process of a city of becoming a smarter city.

To answer this main question, other sub-questions will be tackled in this paper. For each sub-question, a part of this paper is dedicated. Namely, the sub research questions are the following:

- What is 5G and what will it change in comparison with previous network generations?
- What makes a city smart?
- What is the link between 5G and smart cities?
- What are Luxembourg's inhabitants' expectations for the future of the city/country?
- What are the main challenges Luxembourg is facing in its public sector?
- For each sector, how could 5G enhance the situation and help it to tackle its defies?
- How to become a smart city?
- What are the drawbacks of 5G? What are the challenges of Luxembourg in its implementation of 5G?
- What predictions can be made for the future of Luxembourg?

1.4   Research relevance

This paper encounters two specific types of relevance. Indeed, it provides both business relevance as well as scientific relevance.

1.4.1 Business relevance

The business relevance of this research paper is explained by the use and analysis of academic papers' pieces of information. Also, reliable sources such as papers and reports from the European Commission and Big Four companies (Ernst and Young, KPMG, PwC, and Deloitte) are being used.

Besides, interviews with experts of smart cities and 5G as well as a survey have been conducted to gain in-depth knowledge respectively of Luxembourg's challenges and the two main concepts and of the population's expectations and needs for their city/country to become a smart one.

Furthermore, a framework has been created to potentially be used by cities in their process of becoming a smart city.

1.4.2 Scientific relevance

Academic papers are studied in this paper to analyze the differences between 5G and its predecessors. Therefore, this paper's goal is to expose the way 5G could enable Luxembourg to become a smart city, which is enabled by the study of those academic researches. Moreover, a gap between academic literature and reality has been filled in this paper. Indeed, the current situation of Luxembourg that has not priorly been analyzed in the literature. Besides, the scientific relevance of this research paper is explained by the connection between two main topics that are 5G (i) and the concept of smart cities (ii).

1.5 Research methodology

1.5.1 Design research model

The research model has been constituted of interviews and a survey. The interviews served as pre-tests and helped us define what are the current challenges for the public sector. They, therefore, helped us build the survey. Also, the combination of both the survey and the range of interviews allowed us to define and fill the gap between the inhabitants' expectations and thoughts about the current situation of the public sector as well as the future of their country and what the experts and the academic papers think are the biggest challenges in Luxembourg, and, therefore, how could 5G help overcome those challenges. All of this enabled us to answer the main research question "How could 5G enable Luxembourg to become a smart city?".

1.5.2 Experts selection

Three different kinds of experts have been selected for the interviews:

- Experts with knowledge of 5G technologies
- Experts of the public sector and smart cities
- Experts from one specific sector

1.5.3 Experts interviews

Many experts from the diverse studied sectors in this paper have been interviewed in semi-structured interviews. Also, experts of 5G have been interviewed in order to acknowledge their point of view of the technology and to know how this could enhance Luxembourg's activities. This will further be discussed in Chapter Three. Experts from the public sector helped us identify its main challenges that are mobility, healthcare, and housing in the country. Therefore, a focus will be made on these specific sectors.

1.5.4 Survey

The pool of respondents to the questionnaire is constituted by inhabitants of Luxembourg. The goal of this survey was to acknowledge citizens' expectations, needs, and current use of mobility, public healthcare, and housing. Therefore, the survey used in this paper is a qualitative one as the concern is to get the opinion of Luxembourg's residents about the public sector's situation in the country. As the priorly conducted interviews helped us identify the main challenges of Luxembourg's public sector, the survey is focusing on those three sectors.

1.5.5 Research reliability and validity

This research paper provides an interrater reliability as well as an internal consistency: the measures are consistent across participants of both the survey and the interviews. I.e. in the survey we analyze main streams that are similar for everybody.

Moreover, is an exploratory research based on the method of triangulation, which brings validity to the study. Indeed, three research methods have been used: desk research (i) that consisted in analyzing and discussing theoretical literature, interviews with experts coming from different backgrounds and different expertise (ii) as well as an anonymous survey (iii).

1.6 Research scope

The scope of this research paper is to analyze how could 5G enable Luxembourg to become a smart city, and more precisely in terms of mobility, healthcare, and housing. Therefore, different concepts are covered in this paper such as 5G technology, smart cities, mobility, healthcare, housing as well as the current situation in Luxembourg regarding those three specific sectors.

For a matter of time and content constraint, only those three specific sectors have been chosen. As a matter of fact, the reason why those sectors are the most challenging in Luxembourg will be explained in Chapter Four. For the same reason, only raw-technical specificities of 5G will be covered as this topic is in itself a very broad one. Thus, only technical aspects that can affect and enhance smart cities are being discussed.

1.7 Research outline

As it has previously been clarified in this paper, the motivation led us to focus on the emerging tech trend that is 5G, and how this latter is connected to the concept of a smart city. In consequence, as seen in Figure 1., the focus on the fact that 5G is an enabler of specific use cases that determine smart cities leads us to a specific structure of the present research (Figure 2).

Chapter One: Introduction
Chapter Two: Literature review
Chapter Three: Research method
Chapter Four: Findings and discussion
Chapter Five: Drawbacks of 5G and challenges for Smart Cities
Chapter Six: Limitations of the paper
Chapter Seven: Conclusion and recommendations for further research
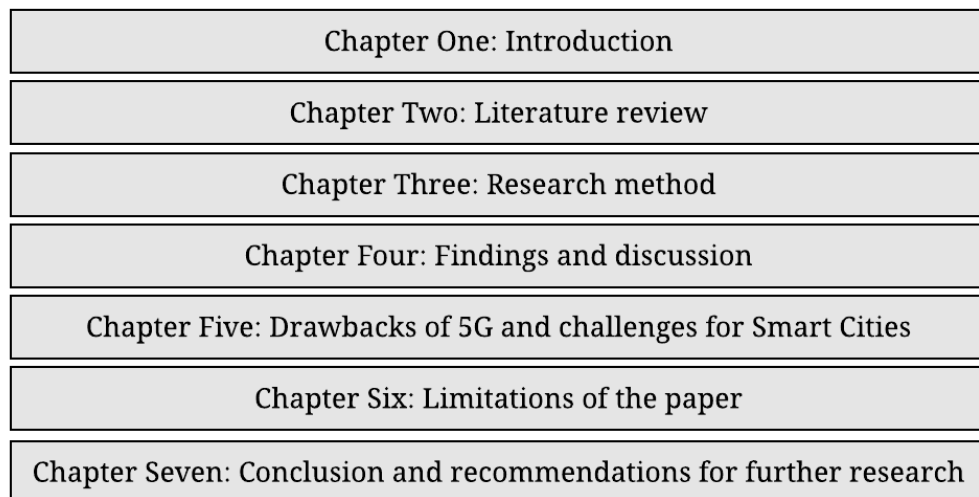
Figure 2. Research paper structure

The whole research will be structured as follows: as a second chapter following the present one, the literature review will be presented to define and discuss the two main concepts: the fifth wireless network and the concept of smart city/country, as well as the

correlation between both concepts. Then, we will present the research method, which will be followed by the findings of the research, which will then be discussed. After this, we will posit the drawbacks of 5G and will present with the limitations of this research, and will finally conclude and make recommendations for further research.

2   LITERATURE REVIEW

The goal of this research paper is to analyze what academic papers discuss about the way 5G could enable cities to become smarter and in this particular case, that it could empower Luxembourg on its way to become a smart city according to the country's current challenges. In consequence, it is essential to analyze in this literature review three distinct kinds of academic papers: the ones that examine 5G in general (i), the ones that tackle the smart city concept (ii) and the ones that combine both those topics i.e. 5G and smart cities and explain what 5G can bring to intelligent cities and how it has the opportunity to enhance them.

We will firstly be discussing 5G, then we will tackle the smart city concept and will finish this literature review by examining the bond between 5G and smart cities.

2.1   What is 5G?

For a matter of accurateness and preciseness, it seemed important to get access to recent research papers for them to be as relevant as possible regarding 5G technology. Indeed, as 5G is very recent and the topic is still being analyzed and researched, only sources that were written after 2018 are being discussed in this paper regarding 5G.

Moreover, for a matter of time-constraint and content-constraint, the deep technical aspects of 5G will not be defined, as this would not help us define its importance for intelligent cities. In consequence, only the raw technical aspects of 5G technology will be discussed.

2.1.1   Introduction to the wireless mobile communication

Wireless mobile communication is a network that is being used since the first mobile phone. Indeed, according to Nalin, D. et al. (2019), it is a fastly flourishing industry since the first mobile phone was commercialized in 1979.

Wireless mobile communication started its existence with 1G from 1979 and evolved from 1G (first-generation) to 5G (fifth-generation) in forty years (Nalin, D. et al., 2019).

2.1.2 The evolution from 1G to 5G

2.1.2.1 *First-generation*

Although 1G represented a huge step to achieve mobile communication, it had only a few advantages. Indeed, it is defined as the first-generation mobile telecommunication. It was first introduced in 1979 and allowed voice calls between consumers within the same nation. Moreover, some ideas of the first generation are mined for the following generations, such as cells and frequency reuse.

However, 1G had some disadvantages such as a limitation in terms of coverage area mobile network, a low calling limit, a poor data rate speed as well as very low privacy and security (Nalin et al., 2018).

Besides, according to Sharma (2013), the analog systems were allocated a 40-MHz (MegaHertZ) bandwidth.

2.1.2.2 *Second-generation*

According to Nalin et al. (2018), the second generation is established on the global system for mobile communication (GSM). It has a speed of between 14.4kbps (kilobits per second) and 64kbps. It adds to 1G the possibility to send short message services (SMS), multimedia, and picture messages (MMS) as well as emails. Also, in comparison with 1G, the second generation improved privacy.

However, it has some fails such as the fact that it is not possible to send videos, 2G has a low data rate, and it is necessary to have a high digital signal to connect mobile phones.

2.1.2.3 *Third-generation*

The third generation of wireless technology was established in 2000 (Sharim, 2013).

A higher speed is provided by 3G in comparison with 1G and 2G. The speed is between 144kbps and 2mbps (megabits per second). The 3G is a big evolution as it enables users to send SMS, MMS but also includes multimedia, text, and limited Internet access (Nalin et al., 2018).

2.1.2.4 *Fourth-generation*

The fourth-generation emerged in 2010 (Sharim, 2013). According to Nalin et al. (2018), 4G provides a much better area coverage than previous generations. The data rates of

communication are higher and better quality video streaming. The frequency band range provided by the fourth generation is between 2-8GHz (GigaHertz) and the speed goes up to 50Mbps. Moreover, worldwide roaming is made possible with this generation, which makes possible cellular communication anywhere.

2.1.2.5 Fifth-generation

According to Nalin et al. (2018), 5G has as objective to procure an entire wireless communication with almost no restrictions. They also posit in their book "*5G enabled secure wireless networks*" that in 2018, six billion people had a smartphone in their possession which enables one to assume that someday, all those people if not more will be using 5G.

South Korea, the United States of America, and Switzerland were the first countries in which 5G mobiles offerings have been commercialized in April 2019. In February 2020, VIAVI, the American company of analysis of information Networks identified thirty-four countries in which 5G was accessible. The top-ten countries with the highest number of 5G connected cities is constituted of South Korea with eighty-five cities, China: fifty-seven cities, USA: fifty, UK: thirty-one, Saudi Arabia: twenty-four, Spain: fifteen, UAE: eleven, Australia: ten, Germany: ten and Romania: ten (VIAVI, 2020).

Table 1. Summarized evolution from 1G to 5G (adapted from Nalin et al., 2018; and Sharim, 2010)

	1G	2G	3G	4G	5G
Implementation date	1980	1990	2001	2010	2019
Advantages	Cells and frequency reuse The first success in achieving mobile communication	Secure Better battery capacity	Faster data transmission and allows location-based services	Speed Worldwide roaming	Better coverage of data Low latency Increased reliability
Drawbacks	Little coverage Low calling limit, Slow data rate Poor privacy and security	No videos, Low data rates, Poor area coverage	Expensive, Higher bandwidth requirements	Expensive, Hard to implement, Higher battery usage	Need for 5G-compatible devices to be used
Data bandwidth	2Kbps - 14.4Kbps	14.4Kbps - 64kbps	2Mbps	100Mbps	10Gbps
Frequency	800MHz	1900MHz	2100 MHz	2600MHz	3-90GHz

2.1.3   Overview of 5G technology

This overview of the technology includes an introduction to the fifth-generation of wireless mobile communication as well as 5G key attributes.

2.1.3.1   *Key attributes of 5G*

Nalin et al. (2019) state in their book that 5G has many features such as a better speed of data transfer rates, a larger memory than previous generations, a high definition quality impression, a much faster uploading and downloading speed thanks to its faster speed. KPMG, Rivett & Holt (2019) confirm this by arguing that that the fifth-generation wireless technology has five main characteristics that are capacity, reliability, latency, bandwidth, and efficiency.

Deloitte (2018) in its report "*5G mobile technology*" defines the latency of 5G as the rapidity at which data can be downloaded or uploaded. When a mobile network is faster, this means in consequence that the waiting time on the Internet is lower. According to the

report, 5G offers speeds of up to10Gbps which represents more than a hundred times what 4G offers. The same authors also state that this low latency can be essential for enabling IoT and add that this would enable users to link multiple sensors and connected devices. The same report states that in 2017 there were 8.4 billion connected devices and an estimation of 20.4 billion is made for 2020. Also, Nystrom et al. (2019), in their article "*Business opportunities in 5G mobile technology*", add that 5G is designed for very low latency applications with high traveling speeds of the users, as well as greater accuracy in some features such as the geolocalisation of the users, bigger data rates and lower energy consumption. The authors also posit that, as 5G is quite recent as it started its implementation in the world in early 2019, the business opportunities of this technology are still being researched. Indeed, the authors state that the technology could be an enabler of new applications in vertical industries such as education, healthcare, automotive and transport, energy, but also manufacturing, financial services, and agriculture for example. Indeed, communication and connectivity do not necessarily constitute the core of these industries, thus 5G acts as a technology creating an ecosystem that can meet the emerging technical needs of those sectors. Therefore, an important defy for the ICT industry is to identify application areas and deployment opportunities that would create value for all the different stakeholders (Nystrom et al., 2019).

Thereafter, Marabissi et al. (2018) complete these works of literature by defining what Nystrom et al. (2019) are discussing in their paper as network slicing. It has been identified by the authors as "*one of the key drivers of 5G systems enabling the support of a broad variety of vertical markets that originate many and very different use cases, and, thus, different requirements*". A common network setting cannot meet this large range of requirements and the deployment of individual mobile network solutions for every of the use cases in considered as unfeasible by the authors. On the contrary, network slicing would enable to compose and manage "*dedicated end-to-end logical networks with specific functions, without losing the economies of scale of a common physical infrastructure*" (Marabissi et al., 2018).

Besides, as discussed by KPMG, Rivett & Holt (2019), 5G is also very reliable. Deloitte (2018) confirms this by arguing that 5G assures that the network will always be on, and, in consequence, avoid every type of outages.

This reliability coupled to the low latency of 5G is called URLLC: Ultra-Reliable-Low-Latency-Communication (Nalin et al., 2019).

Nystrom et al. (2019), posit that URLLC is a crucial feature of 5G and that it could be defined as the services and applications requiring reliability in the data communication between two parts, i.e., from one end to another. URLLC allows the use of certain applications and services by fulfilling sub-millisecond latency. As it makes the fifth generation of wireless technology very reliable, it enables use cases such as automated driving, road safety, and traffic efficiency services for mobility or remote surgery for healthcare, amongst others. However, it is being discussed in this same article that the use of the frequencies and who will provide them can represent an issue.

Another key feature of 5G is the improved capacity of the network. Deloitte (2018) confirms this argument by stating that this capacity allows users to avoid network congestion. Indeed, the number of mobile devices using networks is constantly growing which can provoke congestion, but 5G can avoid this phenomenon. Indeed, according to the authors, "*5G networks will utilize several spectrum bands, including those with higher frequencies. This will mean that it can support, at a minimum, 1 million connected devices per square kilometer*".

In addition, Nalin et al. (2019), argue that MIMO (Multiple In, Multiple Out) enhances a greater capacity of the channel and enables a greater amount of data to be sent while improving energy efficiency.

2.1.4 5G enabler of AI, IoT, AR/VR and robotics, drones, industrial automation at massive scale

As previously argued, 5G makes other technologies more capable and more reliable. As a matter of fact, Holt & KPMG. (2020), argue that 5G represents the power behind Industry 4.0 as it is able to connect Machine-to-Machine (M2M), Machine-to-People (M2P) and People-to-People (P2P). Therefore, it is expected from 5G that it will "*unleash the potential of technologies like AI, IoT, AR/VR and robotics*" (Holt & KPMG., 2020).

To this, Deloitte (2018) adds that these very high speeds can create more data-intensive entertainment like Virtual Reality (VR) feasible on mobile networks instead of having to use Wi-Fi.

2.1.5 What are the benefits and new opportunities created by 5G?

In its report, Deloitte (2018) states that 4G and Wi-Fi represented huge advancements in mobile communication so that one can wonder how it would have been possible to make

better changes, and if 5G would only represent an incrementation of what 4G started, or if it would be a real technology revolution for both the customer behaviour and the industry disruption. Therefore, one can wonder if 5G will only be a bit faster than what 4G and Wi-Fi were capable of, or if it would initiate a new era of capabilities while enabling the creation of new business models.

The same report posits that even though 5G is still being developed, it would have the potential to empower many advancements, including digital transformation, making possible faster connections for consumers and businesses.

According to Deloitte (2018), 5G would offer the possibility for multiple industries to change their way of operating. The author argues that the greatest improvements of 5G in comparison with 4G are the speeds it enables, the low latency as well as more lanes in the network that enable a better organization and allocation of the bandwidth, which is aligned with other academic researches as previously discussed.

Moreover, one of the reasons why we need faster mobile data speeds is for video uploading and downloading. Indeed, the report posits that it is expected that seventy-eight percent of mobile data traffic will be by video by 2021, which is sixty percent greater than it was in 2016. 5G technology could provide speeds up to ten gigabits per second (Gbps). In consequence, a subscriber could download a high definition movie in five to ten seconds thanks to 5G, compared with ten minutes for 4G.

In addition, 5G and its low-latency gives a way better reliability to the technology than 4G. 5G enables use cases such as remote surgery, self-driving cars, and an expended Internet of Things that 4G could not.

Furthermore, according to Marabissi et al. (2018), the main difference between 5G and previous networks is the fact that "*The adoption and in-depth integration of a network of verticals, thus enabling the development of new digital services and models. As a consequence, future 5G networks are faced with the challenge of supporting three main categories of use cases: (i) enhanced mobile broadband (eMBB), which delivers gigabytes of bandwidth on demand, (ii) massive machine-type communication (mMTC), which connects billions of machines, and (iii) ultra-reliable and low-latency (URLL) communication*". This would allow fast feedback, which makes the technology ultra-reliable and enables critical use cases such as self-driven cars.

According to Nalin et al. (2019), 4G presents issues such as high power consumption of the devices that use this fourth-generation. They state in their book that, in comparison with 4G, 5G provides an easy rate of the data calls. Indeed, we observe a higher quality

of service which is also much more flexible and with important spectrum management. It is also said, according to those same authors, that 5G provides better efficiency and decreasing costs in comparison with the prior generation.

Moreover, the president of the Arcep (Dofing, 2019) argued that in 2025, it is expected that two-thirds of the population will have access to 5G and assumes that 5G will take over the 4G networks that are beginning to saturate due to the fast growth of the quantities of exchanged data. He also confirmed that 5G will enable the development of smart objects thanks to captors without batteries, which is not possible with 4G.

Therefore, in his article, Zhou (2019) posits that the greatest difference between the fifth-generation and its predecessors is that it is not a single technology but the addition of all current ICTs. This is confirmed by Deloitte (2018). Moreover, Zhou (2019) states that security, coverage, and flexibility have known a big improvement compared with 4G, which actually solves the existing issues of the latter.

Phan & Qureshi (2017), argue in their article "*5G impact on smart cities*" that the fifth-generation wireless technology is a high-speed one that will have the capability and potential to make cities into smart ones.

The same authors discuss the fact that sixty-six percent of the world population is estimated to be living in cities after 2030. Thus, this shows the importance of intelligent cities.

2.2   What makes a city smart?

As the objective of this research paper is to show how 5G could enable cities to become smart ones, it is essential to define the concept of a smart city.

2.2.1   Introduction to the smart city concept

The definition of the smart city is varying between different researches, indeed, there is no consensus of a unique definition. According to Phan & Qureshi (2017), a smart city is about the connection of multiple low power digital devices with each other, to efficiently run few levels of the city: our homes, our offices as well as other places through IoT.

Very close to this first definition, Washburn et al. (2010) posit that a city becomes a smart city once it is using Smart Computing. Smart Computing is in their research paper is defined as "*A new generation of integrated hardware, software, and network technologies that provide IT systems with real-time awareness of the real world and*

advanced analytics". According to the authors, this would help the citizens to make more intelligent decisions about actions that would optimize business processes and business balance sheet results. For a city to become a smart one, Smart Computing is being used to perform its essential services to the public in a remarkably efficient manner.

Other authors go in the same direction such as Anavitarte & Tratz-Ryan (2010) who define a smart city in their paper as "*an urban area functioning and articulated by modern information and communication technologies in its various verticals, providing ongoing efficient services to its population*". Those authors believe smart cities are being enabled by the use of information technology, and see the latter as one of the most essential components of the intelligence of the city.

Nevertheless, other academic authors have different arguments while defining the concept of a smart city, and go beyond the importance of the use of information and communication technologies. It is the case of Hollands (2008) who defines smart cities as an urban naming phenomenon, and more particularly regarding what the label implies, which could actually be identified differently between different actors and in different situations. Boulton et al. (2011) agree with Hollands (2008) as it seems crucial for them to disentangle the distinct aspects of a city as a phenomenon.

According to Mohanty et al. (2016), the attributes of a smart city are sustainability, quality of life, urbanization, and smartness, and four distinct themes of the smart city are identified by the same authors: society, economy, environment and governance. To this argument, other authors such as Allwinkle & Cruickshank (2011); Alves (2007); Caragliu et al. (2011) posit that the capability of a city to sustain social, cultural, economic, and environmental progress makes it smart.

Furthermore, while Washburn et al. (2010) argue that a smart city is mainly for the public and is citizen-centric, other actors such as the European Commission argue that smart cities are for both the citizens as well as the businesses. Also, Washburn et al. (2010) state that a smart city can have many different labels such as, amongst others, intelligent city, information city, urban innovation, creative city, digital city, or knowledge city. It can also be labeled, according to Saraju et al. (2016) cyberville, electronic city, flexicity, telicity, or wired city.

2.2.2   Components of a smart city

According to Gil-Garcia et al. (2015), a smart city has specific component elements that are divided into nine categories:

- Public services category that contains: transportation, safety, housing, health, social services, water, energy and electricity, solid waste, shelter, emergency services, food, culture, tourism, recreation.

- The city administration and management gathering: E-government, performance management, funding, staffing, leadership, vision, policy instruments, policy learning.

- Institutions containing: the institutional type, intergovernmental agreements, and the rule of law.

- Governance, engagement, and collaboration: E-governance, stakeholder, citizen and community engagement, network, partnership, and collaboration.

- Human capital and creativity that contains: creative class, social infrastructure, education, and skilled workforce.

- Knowledge economy and pro-business environment with: knowledge economy, creative industry and entrepreneurship, high-tech industry, and business environment.

- Built environment and city infrastructure containing: environmental and economic sustainability, functional management, and the attractiveness of built infrastructure.

- The natural environment and ecological sustainability with: ecological sustainability, monitoring system, pollution, and attractive natural condition

- ICT and other technologies gathering: broadband, wireless, virtual technologies, ubiquitous accessibility, computing network, and service-oriented architecture.

- Data and information that contains: data management, information processing, and information-sharing.

While according to Mohanty et al. (2016), a smart city has nine distinct components that are: infrastructure, building, transportation, energy, education, governance, citizen, technology, healthcare.

Therefore, if we compare the components stated by Gil-Garcia et al. (2015) and the ones argued by Mohanty et al. (2016) (Table 2).

Table 2. Compared components of a smart city (adapted from Gil-Garcia et al., 2015 and Mohanty et al., 2016)

Components of Gil-Garcia et al.'s paper	Components of Mohanty et al.'s paper
Public services	Transportation Healthcare Energy
The city administration and management	N/A
Institutions	N/A
Governance, engagement, and collaboration	Governance
Human capital and creativity	Education Citizen
Knowledge economy and pro-business environment	N/A
Built environment and city infrastructure	Building Infrastructure
The natural environment and ecological sustainability	N/A
ICT and other technologies	Technology
Data and information	N/A

Once those elements compared, we can see that some of them are correlated, but one can argue that the ones from Mohanty et al.'s paper are vaguer and missing some core elements to makes a city smart such as data and information. However, although they do not represent general categories, specific use cases are being identified as we can notice that some can be gathered in a unique category from Gil-Garcia et al.'s paper.

We can conclude that the literature states that smart cities represent a bundle of distinct components as stated by Gil-Garcia et al. (2015) and Mohanty et al.'s papers, but a universal definition of a smart city cannot be found in research papers, because, as stated by Hollands (2008), the smartness of a city can be evaluated differently from different persons. Most of the academic literature defines a smart city as a citizen-centric town.

2.3   5G linked to smart cities

According to the literature, 5G could bring many advantages for smart cities and could even enable cities to become smart ones.

2.3.1   What can 5G bring to smart cities?

Marabissi et al. (2019) in their research paper state that 5G is an enabler of many use cases such as smart cities. Moreover, the authors posit that 5G is capable of creating an entirely new digital economy while providing an omnipresent network that will enable people, things and services to be connected (M2M, M2P, P2P).

Rao & Prasad (2018) confirm that 5G represents a technology enabler for smart cities. They also argue that IoT is essential for smart cities and is one of the primary use cases for 5G.

2.3.2   Smart City Applications and Services Enabled by 5G

Marabissi et al. (2019) state in their research paper that 5G technology is designed to providing different services that are different in terms of requirements and types of devices. They also argue that while current services are focused on personal communication, on the Internet these will evolve towards the IoT paradigm. Consequently, new 5G macro-applications will emerge such as industrial automation, smart transportation, digitization of the living environment (e.g. with smart homes amongst others), public safety services, telepresence services (e.g. with VR and holograms) and other systems of a public utility such as healthcare.

Rao & Prasad (2018) agree with Marabissi et al. (2019) and confirm that 5G is an enabler of public safety, security, smart homes, smart mobility as well as smart healthcare, smart education, smart grids, amongst others. They explain that those use cases are supported by the big growth of the number of devices such as sensors, cameras, actuators connected to wireless networks as well as by the URLLC.

Moreover, Atalla & EY (2019), state that there are four distinct ways in which 5G will change life in smart cities that are, firstly, by allowing people to move across crowded urban areas with fewer difficulties (i), then, to use data to achieve city operations at an unprecedented scale thanks to the enabled fast transmission of data (ii). The report also confirms that public safety will be improved as well as the automation of emergency

responses (iii) and that 5G will end the digital divide (iv) by enabling everybody to have access to the same opportunities such as education and training programs.

As previously discussed, many technologies constitute 5G. Some of these could enhance smart cities and have been gathered in Table 3.

Table 3. Summary of 5G technologies that could enhance smart cities according to the literature

Technology	Description	Authors
eMBB	Enhanced mobile broadband which delivers gigabytes of bandwidth on demand	Marabissi et al (2018), Nalin (2019), Nystrom (2019)
URLLC	Ultra-reliable and low-latency communication which allows immediate feedback with high reliability for critical use cases	Nystrom (2019), Nalin et al. (2019), Marabissi et al. (2018), Deloitte (2018), Holt & KPMG (2020), Rao & Prasad (2018)
mMTC	Massive Machine-type communication, which connects billions of machines	Marabissi et al. (2018), Phan & Qureshi (2017)
Large scale MIMO technology	Multiple-Inputs Multiple-Outputs multiplies the capacities of a radio link	Zhou (2019)
mmWave	Enables more network capacity by expanding into new spectrum	Holt & KPMG (2020)

As a consequence, many use cases are made possible such as smart mobility, smart housing, and smart healthcare, amongst others (Mohanty et al., 2016, Gil-Garcia et al., 2015 and Atalla & EY, 2019).

2.3.2.1.   Smart mobility

Marabissi et al (2019) in their article posit that "*5G is an enabler of intelligent transportation with many services such as assisted driving, autonomous driving, smart sensors on vehicles, information on traffic and risks, and visual enabled services (see-through)*".

They also state that, in a completely integrated 5G network city, smart mobility is awaited to bear different social challenges. Therefore, having a safe, efficient, reliable, and green transportation is essential. In these circumstances, 5G is visualized as the

ultimate platform to enable smart mobility solutions, and "*cellular-vehicle to everything (C-V2X) functionality will be included as part of the cellular chipsets embedded into vehicles for their vehicle to network (V2N) communications*".

Therefore, the authors argue that smart mobility represents a key driving sector for a potential evolution towards 5G. One of the objectives of the smart mobility platform is to provide two distinct use cases that are the "high connected electric vehicle road monitoring" and the "advanced viability". The prior (i) aims to deploy an electric car park as well as charging points for electric vehicles to monitor the state of the road quality, thus, by observing the presence of holes or traffic conditions for example. This would be enabled by the set up in cars of a black box containing a "*5G module for real-time data transmission to post-processing systems*". Added to the black box, a GPS would be installed in the cars in order to map very accurately the geographic coordinates of the holes or the traffic jams, car accidents, etc. The latter, advanced viability (ii), "*represents connected vehicles that will interchange data with other vehicles and with a control center where data traffic information is smartly integrated with weather conditions, road status, and other information provided by IoT sensors in the city*". Advanced viability's objective is to make vehicles and drivers safer, as well as to enhance the comfort and the driving style of people and to reduce congestions, which means a pollution decrease. All of this is made possible thanks to using real-time information, to the data transmission as well as to the high-reliability 5G provides.

To this, the European Commission (2016) adds that a city, run as an integrated system, would be able to re-think its activity if an incident occurs e.g. car accidents, by temporarily re-routing emergency services, which would avoid traffic jams, or by sending additional public transport services to the parts of the city affected by the incident.

Deloitte (2018) posit that, as discussed earlier, the high reliability provided by 5G networks makes it an enabler of critical services, as it would avoid all kind of outage. This would, therefore, enable use cases such as self-driving cars that need extremely good reliability. The report exemplifies this by arguing that outages would have very critical and important consequences on driverless cars or drones for example; "*5G is expected to offer ultra-reliable service options, including 99.999% network availability for mission-critical 'ultra-reliable' communications*". Thereafter, the report posits that 5G could be able to lower road accidents by deploying local warning systems through vehicular communications (V2V).

Besides, many 5G enabled vehicles features are identified by the authors, such as a built-in driver assistance system based on 3D imaging and built-in sensors, but also the capability of the vehicles to detect and identify safety-critical situations, such as accidents within reach of the car and other hazardous road conditions. 5G enabled vehicles could also have augmented reality dashboards which would overlay information on top of what a driver is seeing through the front window, but also remotely controlled or self-driven vehicles.

Therefore, two types of communication would exist; data-transmission between self-driving cars (V2V) as well as data-transmission between cars and infrastructures (V2I).

The data of V2V communication would include speed, location, loss of stability, or the direction of travel for example, while V2I communications would enable vehicles to exchange data with roadside installed infrastructures or satellites for example about the quality of the road, an icy road, or potential hazards.

Such status information or event information could, therefore, be sent to other vehicles or to a base station, where the data can be aggregated and later on sent to other vehicles for them to make use of it.

Furthermore, Atalla & EY. (2019) argue that the features presented by Deloitte (2018) would help people move across urban areas with much more ease. Indeed, as sensors and devices will be powered by 5G networks, we will observe a growth of the use of connected autonomous vehicles as well as intelligent transportation networks.

2.3.2.2. Smart housing

One of the objectives of smart cities is the global management of resources, therefore, the construction of smart houses becomes a necessity for cities to be intelligent according to Elariane & Dubé (2019).

Nagar et al. (2016) defines the smart home as a home that uses a "*combination of appliance-level energy meters, context sensing equipment, automated relays, and user interfaces for detecting and curtailing energy and resources waste*".

Elariane & Dubé (2019) posit that there are four main components of smart buildings and houses that are distributed solar generation, smart meters (with electricity smart meter, gas smart meter and water smart meter), in-home display with user interface and home area network.

According to Rao & Prasad (2018), a smart home must accomplish the required needs of the residents. Those requirements, are composed of remote monitoring and control of

the homes for security, surveillance and management of children and elderly for example. The authors add that a smart home needs to have a home gateway platform which would gather all the different technologies needed as its inputs and that must combine those technologies and create a communication with the centralized monitoring system. Therefore, according to their research paper, some use cases are being added to the ones Elariane & Dubé (2019) argued. Those use cases are: remote home security monitor and control, and remote control of home appliances like heaters, fridges, lighting systems, water sprinklers etc.

In addition, Elariane & Dubé (2019) are expecting homes to become huge essential sources of information, and that they, in consequence, would generate a large amount of data.

Furthermore, the literatures adds that the large bandwidth offered by 5G and the ability to connect many devices to each other could unleash cloud gaming at home and would change the way people use AR and VR. In addition, one of the biggest reasons for people to adopt 5G is in order to have a greater connectivity inside the home (Arkenberg & Deloitte, 2020).

Moreover, Arkenberg & Deloitte (2020) also argue that 5G is expected to provide speeds as good, if not better, than cable or fiber. Although, the advantage 5G has on the cable or fiber, is that it could enable businesses (i.e. providers) to meet the users' increasing need to watch and share video while building capabilities for next-generation media and entertainment experiences. It would therefore enable the creation of enhanced customer experience and greater offer depending on the latter's needs.

Marabissi et al. (2019) confirm that smart homes would be enabled by the digitalization of the living environment enhanced by 5G. This could be coupled with waste recycling, environment sustainability, smart water etc.

Furthermore, Ericsson (2019) affirm that 5G is an enabler of human-machine interaction, which, in the case of smart houses can show some benefits such as "*a tactile internet and smart interactions M2P as well as potential new business opportunities as the main difference from M2M*". As an opportunity area, we also find child monitoring (as confirmed by Rao & Prasad, 2018), which could make the house even smarter.

Also, the report states that sensors networks are a use case enabled by 5G which has as opportunity area smart buildings. In this case, the benefits would be the maximization of the productivity in the indoors but also the development of business openings and

business models through monitoring, tracking and automation capabilities in larger scales.

2.3.2.3.   Smart healthcare

Smart healthcare is a largely discussed topic in the literature. Indeed, Marabissi et al. (2019) stated that 5G is an enabler of smart health and e-health. Indeed, in their article, they discuss the case of the implementation of 5G in two Italian cities and the objective for e-health was to develop a platform for telemedicine, telemonitoring and analysis of behavioural habits, that would have the ability to enable processes with the aim to certify the continuity of care and assistance. In this situation, the gathered data and the feasibility of remote assistance allow doctors to set an interactive relationship with patients, providing them with a personal therapeutic path. This solution justifies costs and supports the conception of high-added-value services able to fulfil the needs of both inhabitants and corporate customers, and provides a series of health services that can be applied remotely. Furthermore, the use of drones for the quick transport of medicines and medical equipment will also be performed.

The same authors also state that the use of smart sensors is enabled by 5G. Therefore, as suggested by one of the interviewees, the equipment in hospitals could be tracked and thus easily found. Also, 5G is said in their research paper to be able to make more accurate and efficient remote healthcare possible thanks to the use of AR/VR and robotic surgery. As a matter of fact, mobile networks have enabled telehealth as well as telesurgery thanks to a robot, 3D cameras and a special console. 5G, thanks to its URLLC aspect, is an enabler of such use cases and would most supposedly in the future enable telesurgery at even greater distances.

Besides, Deloitte (2018) affirms that there are several 5G characteristics that can support healthcare use cases such as bandwidth, URLLC to avoid outages, telemedicine through audio and videoconferencing, tele radiology, remote patient monitoring (thanks to wireless sensors), remote surgery, interactive 3D brain imaging etc. Similarly, Atalla & EY (2019) argue that 5G enabled technologies will allow healthcare providers to provide rapid care to many, and allow patients to age at home.

Those arguments are supported by Ericsson (2019) that discuss the benefits of smart health such as an increased efficiency and a reduction of the costs.

2.4   Conclusion of the literature review

5G is expected to be disrupting the decade ahead of us (Nalin et al., 2019; Deloitte, 2018; Nystrom et al., 2019; KPMG, Rivett & Holt, 2019; Dofing, 2019) and is an enabler of many use cases such as smart cities (Holt & KPMG, 2020; Marabissi et al., 2018; Deloitte, 2018; Phan & Qureshi, 2017; Rao & Prasad, 2018). Smart cities contain many elements of which, amongst others we can find smart mobility, smart housing as well as smart healthcare (Mohanty et al., 2016; Gil-Garcia et al., 2015; Atalla & EY, 2019).

Therefore, the papers mentioned in this literature review, related to 5G, smart cities and the ones that link them both, all enhance our research paper by contributing to the latter by letting us analyze the possibilities 5G could offer for a city to become smart or smarter. This, later on, enabled us to analyze the gap between literature review and real situation in Luxembourg.

3   RESEARCH METHOD

The research method of this research paper comprises two main methods: a pool of interviews as well as a survey are being conducted.

The interviews will serve as pre-tests and help us define what are the current challenges for the Public Sector in Luxembourg and will then allow us to build the survey.

In addition, the combination of both the survey and the range of interviews will allow us to define and fill the gap between the inhabitant's expectations (which represents the second research question) and what the experts and the academic papers think are the biggest challenges in Luxembourg, and, therefore, how can 5G help to overcome those challenges.

All of this will allow us to answer the main research question "How could 5G enable Luxembourg to become a smart city?".

3.1   Interviews

It seemed crucial to convey some interviews before building the survey in order to gain experts' knowledge.

3.1.1   Presentation and interviews guides preparation

Both the presentation and the preparation of the interview guides are critical elements for the interviews. Indeed, those are the elements that will interest the interviewees and give one the envy to reply to our interviews.

Moreover, those are two primordial steps in order to allow an easy analysis later on.

3.1.1.1   *Presentation*

The goal of the interviews in this research paper is both to define a gap between experts' points of view and academic literature mindset as well as to gain knowledge about smart cities and 5G.

3.1.1.2   *Information to be gathered*

There are three distinct types of information to be gathered during these interviews that are: the main challenges Luxembourg is currently facing (i), the main aspects of 5G seen by experts (ii) and the main aspects of smart cities in the experts' point of view (iii).

These pieces of information that are needed allowed us to build distinct interview guides (Appendices 2, 3, 4).

3.1.1.3 Population to be interviewed

We identified four types of people to be interviewed that are: experts with a technical background, herein, with knowledge of 5G (i), experts of the public sector (ii), experts that have knowledge about smart cities (iii), experts that have specific knowledge of one of the identified challenging sectors, herein mobility, healthcare and housing (iv).

3.1.1.4 Interviewing method

In order to gain the most knowledge possible and accurate, personal semi-structured interviews have been chosen as the most efficient method.

Indeed, personal interviews are interesting to conduct, as one may be certain that the interviewee does not receive any help answering the questions, and is, therefore, honest and ensures the interviewer of the completeness of his/her answer. Moreover, personal interviews give the opportunity to analyze the validity of the respondent's answers by observing non-verbal indicators. This is particularly useful when discussing sensitive issues such as herein the current challenges Luxembourg is facing and the drawbacks of 5G. In addition, it can facilitate comparability by ensuring that all questions are answered by each respondent.

It is noted by academic authors that personal interviews lead to a higher response rate. Indeed, face-to-face interviews empower the interviewees to answer to every question.

3.1.2 Interview guides construction

Three distinct interview guides have been built; one relating to 5G (i), another one related to the public sector's challenges, and smart cities (ii), and a last one related to healthcare (iii).

3.1.2.1 5G interview guide

This interview guide is divided into three main parts that each contains three questions. The first part contains 5G-specific questions (i), the second part consists of Luxembourg-specific questions (ii), while the third and last part is built with smart city-specific questions (Appendix 3).

This interview guide is being introduced with a short presentation in order to explain the motivation and background of this research and to posit the role and the importance of the information the interviewee could bring: "First of all I would like to thank you for your time and for your help. In order to set the background, I am a Master student in Management of IT. I have to write a thesis for which I chose the following topic: "Luxembourg's evolution from city to smart city with 5G".

For this matter, I am focusing on public sector and more especially on housing, healthcare, and transportation.

Therefore, my goal is to know how 5G could enhance those sectors in Luxembourg, and be useful for them to overcome the challenges the city/country is facing. In my questions you will find 3 main divisions:

- 5g (in order to acknowledge your thoughts)
- Luxembourg
- Smart city

Please, be as specific as you can, and give as many details as you can".

This introduction is followed by questions per part:

- 5G-specific questions

  The aim of this first division is to gain general knowledge about 5G and to be able to define a gap between the interviewees' answers and the academic literature mindset about this trendy technology. Moreover, as 5G is quite new, there are not a lot of academic papers relating to the topic yet. This part contains three distinct open questions: "According to you, what are the main advantages of 5G?", "According to you, what are the main disadvantages/risks/challenges of 5G?", "In your opinion, what are the main differences between prior generations such as 4G and 5G?".

- Luxembourg-specific questions

  This second part of the interview guide aims to define the readiness of Luxembourg to have 5G. It contains three open questions: "What infrastructures should be set for 5G implementation? - Is Luxembourg ready for the implementation of 5G?", "According to you, what will be the benefits of implementing 5G in Luxembourg and what will be new in comparison with the use of 4G?", and, "What do you think will be the main challenges Luxembourg

will face while implementing 5G? - and more especially in terms of healthcare, mobility, and housing".

- Smart city-specific questions

This third section of the interview guide has the objective of understanding the link between 5G and smart cities, and analyze how could 5G help Luxembourg becoming a smart city. It contains three open questions: "How do you think 5G could enable Luxembourg to become a smart city or even a smart nation?", "How do you think 5G would impact/challenge and benefit healthcare, housing, and mobility in Luxembourg?", and, "What do you think would be the greatest area of improvement in the public sector? Why?".

3.1.2.2 *Public sector and smart cities interview guide*

This interview guide is divided into three main parts. The first part contains smart city-specific questions (i), the second part consists of Luxembourg-specific questions (ii), while the third and last part is built with smart 5G-specific questions (Appendix 2).

Just like for the 5G interview, this interview guide is being introduced with a short presentation in order to explain the motivation and background of this research and to posit the role and the importance of the information the interviewee could bring.

This introduction is followed by questions per part:

- Smart city-specific questions

"According to you, what makes a city smart?, I have found that a smart city, according to research papers has several components; (Appendix 2) What do you think about it? Would you add/delete some components from it?", "In general, according to you, what are the biggest projects/challenges for a smart city?", "In general, for a city to be smart, what are the biggest challenges in terms of: health, mobility, and housing?"

- Luxembourg-specific questions

"Are you aware of the biggest challenges Luxembourg is currently facing?", "Therefore, what are the biggest challenge for each of those sectors?", "Could you say that Luxembourg is a smart city? Why?", "How could Luxembourg become a smart city? And more especially, how could Luxembourg become a smart city in terms of: health, mobility, and housing?",

- 5G-specific questions

"Do you have some knowledge about 5G? - If yes, How do you think it could enable Luxembourg to become a smart city? - If no: 5G is the fifth generation of wireless technology, advances mobile technology in speed, number of permissible connections, latency, capacity, and reliability. It can improve communication between people, but also enable people to interact with the growing ecosystem of connected machines around them. The reality is that 5G will be the catalyst to significant long-term changes in the way people communicate, and what gets communicated. 5G can deliver private, secure and reliable communications, massive M2M (Machine-to-Machine) and IoT communications, real-time data transmission, and enhanced tracking of assets.", "According to that, do you have an idea of what could be the benefits for the public sector in Luxembourg with the deployment of 5G? Above all in terms of mobility, health, and housing", and "How do you think 5G would impact/challenge and benefit public sector?".

3.1.2.3   Healthcare interview guide

This interview guide has been built in order to interview people that have knowledge about the healthcare situation and challenges in Luxembourg. Indeed, it was easy to identify the main challenges in terms of mobility and housing via interviewing inhabitants of Luxembourg. Nevertheless, healthcare challenges seemed easier to identify from the inside, and, therefore, by interviewing experts from the domain.

The interview guide has been built with a short introduction and presentation followed by the questions (Appendix 4).

The introduction is the following: "First of all, I would like to thank you for your time and for your help. In order to set the background, I am a Master student in Management of IT. I have to write a thesis for which I chose the following topic: "Luxembourg's evolution from city to smart city with 5G". For this matter, I am focusing on the public sector and more especially on housing, healthcare, and transportation sectors. Therefore, my goal is to know how 5G could enhance those sectors in Luxembourg and be useful for them to overcome the challenges the city/country is facing. In the herein interview, we will only talk about the healthcare sector, as your expertise on the latter can add crucial insights to my research. Please, be as specific as you can, and give as many details as you wish"

Following this introduction, we find in the interview guide some open-ended questions: "According to you, what are the main challenges the hospitals are facing in Luxembourg?", "Do you have an idea of a way those difficulties could be minimized?", "Do you have an idea of what could be useful for the hospital to set up for the future?". Following those questions, a short introduction to 5G has been integrated in the interview guide: "5G is the fifth generation of internet mobile connectivity. It allows higher speed for downloads as well as much faster sending of data, a larger coverage, and more stable connectivity". Following this short presentation of the 5G technology, questions related to the topic are being asked: "What do you think 5G could enable and enhance within the hospital?", and, "Do you have anything else to say related to healthcare?".

3.1.3 The pool of interviewees and conduction of the interviews

A pool of different experts has been defined and those people have been contacted prior to the interviews in order to set the background and to explain the objective of those interviews but also to make sure those potential interviewees had knowledge about three different topics:

- Smart cities
- 5G
- Luxembourg's current challenges

Some of the contacted people were experts of smart cities and current public sector challenges – mainly about mobility, health, and housing. Others were experts about 5G and some had knowledge about both topics but were mainly an expert on either 5G or smart cities topic. One person was working in a hospital in Luxembourg so she had expertise in the current situation in Luxembourg's hospitals.

As a priority, it was important for this paper's relevance to make sure of the main current challenges in the public sector. After researches, we could say that the main challenges Luxembourg's public sector is facing are gathered in three sectors: housing, healthcare, and mobility.

Once this finding has been confirmed by public sector experts, we could conduct interviews which goal was to assess what are the challenges in terms of mobility, healthcare, and housing.

An initial pool of about fifteen interviewees has been defined. Out of these fifteen people contacted by emails, only six replied. Therefore, six people were interviewed and each of those interviews was conducted by video-call.

As discussed in the previous part of this chapter (3.1.2. Interview guides construction), different interview guides (Appendices 2, 3 and 4) have been built, depending on the interviewee's expertise. An interview guide for 5G, another for the public sector's challenges and smart cities as well as one for the healthcare sector.

As those interviews served as a pre-test for the construction of a survey, once the results have been evaluated, a questionnaire has been built.

The interviews analysis method is explained in Appendix 4.

3.2   Survey

The main goal of this survey is to answer the second research question i.e. "What are Luxembourg's inhabitants' expectations for the future of the city/country?".

The foundation of the survey was built based on the prior conducted interviews and results found.

3.2.1   Presentation and survey preparation

The survey presentation and preparation represent two essential points to inspire the potential respondents and motivate them to answer the survey.

Those are two steps to be carefully completed in order to make the survey as complete as possible and to make the analysis of the latter easier.

3.2.1.1   *Presentation*

This qualitative survey has as goal to define Luxembourg's inhabitants' needs, expectations, mindsets and habits about their life in the country as well as about their thoughts regarding 5G.

The main aim of this questionnaire is, therefore, to answer to the following problematic: What are Luxembourg's inhabitants' expectations for the future of the city/country?

3.2.1.2   *Information to be gathered*

In order to answer to this previous question, we need diverse pieces of information to be gathered such as:

- Inhabitants' mindset regarding both their lives in the country and 5G,
- Inhabitants' expectations regarding the future of the country,
- Inhabitants' current needs and wants.

3.2.1.3 *Population to be interviewed*

Luxembourgish and non-Luxembourgish inhabitants of Luxembourg are targeted to be interviewed. We will focus on people in a specific age range: people from around twenty to around sixty-four years old. Indeed, we can assume that people of this age are the most likely to have the information we need as they are old enough to have more perspective on life than younger people. Also, this range of people has been chosen as it seems to be the most accessible via the Internet as the survey has been administered way online.

3.2.1.4 *Sampling method*

In this study, we will use an empirical sampling method that is quota sampling. It consists in studying the structure of the population on the basis of some variables (that could be the gender, the age, etc.). Here, we will choose the age variable. Accordingly, the objective is to retain a population of individuals from twenty to sixty-four years old. Then, it will allow us to build a smaller representation of reality.

Thus, we are looking to interview people that are the most likely to have deeper insights about the way of living in Luxembourg as well as to have an opinion about 5G.

3.2.1.5 *Sample size and calculation*

The number of people to be interviewed will be calculated by the sampling size in order to represent Luxembourg's population and not to misrepresent the results.

This sampling size is calculated thanks to three distinct parameters that are (i) the confidence rate, (ii) the error margin and (iii) the estimated prevalence.

- The confidence rate

It represents the representativity degree of our sample. We will use a 95% confidence rate with a standard value of 1.96.

- The error margin

The error margin allows one to represent the vagueness up or down that we will obtain during our study. Here, we will take a 10% error margin.

- The estimated prevalence

The estimated prevalence is the last parameter to be used to define the sampling size. It represents the assumed proportion of individuals with characteristics given in our population, namely, people that have insights about everyday life in Luxembourg and that would have an opinion about 5G. The 1st January 2018, Luxembourg registered 613,900 residents.

In 2018, the Grand-Duchy registered an average of 63.7% that were between 20 years old and 64 years old. The number not being accessible yet for the year 2019 nor for 2020, we can assume that it should still be around 63.7%. In consequence, for a matter of adequacy, we will be re-using this percentage as an assumption for the current year.

This number represents the number of people in the age of working. For the pool of respondents, we are looking for people that are approximately this age (twenty to around sixty-four years old) for multiple reasons: (i) firstly because this range of people is the most potentially interested in what is happening in their country but also the most observant ones. Moreover, (ii) the survey is built online, and one can assume that this range of people are the ones the ablest to use the Internet and technological devices. Also, (iii) we can assume that this range of people is the most open to change and to the use of new technologies.

Therefore, 63.7% of twenty to sixty-four years old of the 613,900 residents represent a total of 391,054 people. This number represents our targeted population for the survey.

Thanks to the following formula, we will be able to determine the minimum sample size:

$$n = t^2 * p(1-p) / e^2$$

For which:

n = minimum sample size for meaningful results,

t = confidence level

e = error margin

p = estimated prevalence

Therefore, with a confidence level of 1.96, an error margin of 10% and an estimated prevalence of 0.637, this gives us the following calculation:

$$1.96^2 * 0.637(1-0.637) / 0.1^2 = 88.83$$

Therefore, in order for the data analysis to be as precise as possible, a minimum of eighty-nine people have to answer the survey to have meaningful results.

3.2.2   Survey construction

3.2.2.1   *Presentation and objective*

The goal of the questionnaire is to gather more in-depth information from fewer respondents than it would have been done with a quantitative survey. More open questions have been implanted in the survey in order to get greater depth and personal details of people's opinions, feelings, and expectations. (Appendix 5).

As it is important for this research paper to have both objectivity and subjectivity in the respondents' answers, it is crucial to balance open and closed answers in the survey. Indeed, closed-ended questions are easier for the respondents and are less time-consuming than open-ended questions. This is why the survey is constituted of both open- and closed-ended questions so that the respondent would not give up on his answers, and would still be precise on the few open questions.

3.2.2.2   *Survey structure*

The survey is made of six distinct sections (Figure 3).

| Section One: Smart Luxembourg |
| Section Two: Transportation in Luxembourg |
| Section Three: Housing in Luxembourg |
| Section Four: 5G |
| Section Five: You are |
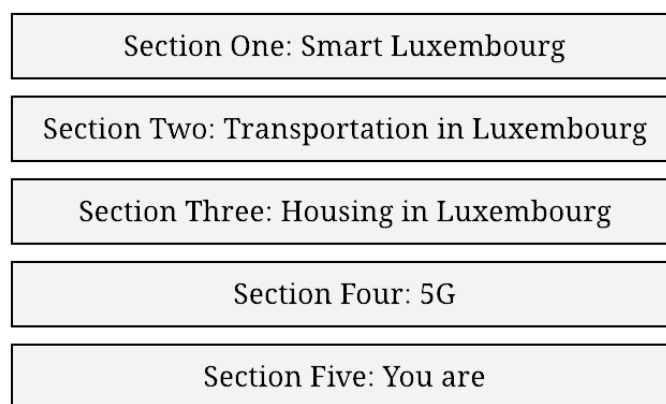
Figure 3. Structure of the questionnaire

The first section is a description of the survey and its goal. It is constituted of a few paragraphs: "If you are a resident of Luxembourg, this survey is made for you! This survey is for you to give your opinion about your life in Luxembourg, your needs, as well as your expectations. This would help me identify the general mindset in the country regarding what technological innovations could provide for the country via 5G. Your response to this survey is anonymous and will be highly appreciated as it will help me develop my Master's Thesis, which topic is "Luxembourg's evolution from city to smart

city with 5G". Your collaboration will contribute to helping me pass my Master's degree in Management of IT. A focus will be made on housing, transportation, and mobility in Luxembourg; so feel free to share your thoughts about your everyday life in the Grand-Duchy. Answering this survey won't take you more than 5 to 10 minutes. Thank you so much in advance!"

The goal of this small paragraph is to explain the background of the study to potential respondents while making an attempt to attract people from the target.

The second section of the survey is the first of the three main parts, which is "Transportation in Luxembourg". It contains a short description("This section is for you to give your opinion on your mobility experience in Luxembourg.") and five questions. The following questions are being asked in that part:

- "How would you rate your overall mobility experience in Luxembourg?"
- "What kind of transportation do you mainly use on a routine basis?"
- "How would you rate each of those criteria?". The criteria being: "Availability of information, Traffic, Quality of the roads, Public transportation, Parking possibilities" and the rating scale goes from "Excellent" to "Very poor"
- "How you describe the overall mobility situation in Luxembourg?"
- "What would you improve/set up/change about transportation in Luxembourg?". Here, an open answer is available for the respondent to have the possibility to express him/herself.

The goal of this second part of the survey is to make a focus on mobility and to acknowledge the citizens' thoughts about their experience with it.

The third section is called "Healthcare in Luxembourg". A short description is displayed: "In this section, you can express your feelings about your healthcare experience in Luxembourg". It contains a few questions:

- "How would you rate your overall healthcare experience in Luxembourg?". The respondent can rate his experience on a scale going from zero being "Very poor" to five being "Excellent". This type of scale has been chosen so that the respondent can really position himself and not rating a "middle" situation. This will help the data analysis.
- "How often do you need the use of healthcare?". Here, the respondent has the choice from "Less than once a year" up to "Few times a week".

- "How would you describe the healthcare system in Luxembourg?". The respondent can reply to this question with an open answer, and therefore, express himself honestly without any bounded rationality that the questionnaire can have in other questions. The difference of this question with the first question of this section ("How would you rate your overall healthcare experience in Luxembourg?") is in the shape of the answer. Indeed, as this survey is a qualitative one, it is crucial that the respondent can express his ideas, needs, and habits.

- In the same kind of the previous question, the last question of this section is "What would you improve/set up/change in healthcare in Luxembourg?"

Then, the section "Housing in Luxembourg" is displayed with a short description: "Here is the section in which you can express your feelings about the housing situation and your housing experience in Luxembourg". It contains three different questions:

- "How would you rate your overall housing experience in Luxembourg?". Here, the respondent can position himself on a scale from 0 being "Very poor" to 5 being "Excellent". This type of scale has been chosen for the same reason than for the first question of the previous sections.

- "How would you describe the housing situation in Luxembourg?". An open answer is expected from the respondent.

- "What would you improve/set up/change in housing?". Here too, the respondent can express himself thanks to a required open answer.

The fifth section is "5G". It contains a description of what 5G is and a few questions. The description displayed is the following: "5G is the fifth generation of wireless technology, advances mobile technology in speed, number of permissible connections, latency, capacity, and reliability. It can improve communication between people, but also enable people to interact with the growing ecosystem of connected machines around them. 5G is supposed to deliver private, secure and reliable communications, massive M2M (Machine-to-Machine) and IoT communications, real-time data transmission, and enhanced tracking of assets. Source: KPMG, Unlocking the benefits of 5G for enterprise customers".

This description has a neutral tone in order to let the person replying to the questionnaire to make his own mind about this new technology. Otherwise, positioning the description as a positive or a negative one could have biased the respondent's answers.

The questions in this section are the following:

- "How soon do you think 5G should be used in Luxembourg in those three sectors" (i.e. mobility, healthcare, and housing). The answer is based on a multiple-choice type of answer. For each sector, the respondent can rate either "As soon as it is available", "Within a year after it is available", "Within two to five years after it is available" or "In more than five years after it is available"

- "Do you think 5G would benefit the public sector?". The possibility of answer is a rate on a scale from 1 to 5, the former being "Strongly disagree" and the latter being "Strongly agree"

- "Would you fear:
  - Health issues
  - Reliability
  - Data protection
  - Environmental issues

  The respondent can answer to this question by rating each criterial either "Extremely", "Moderately" or "Not at all".

- "Would you have other fears regarding 5G?". A short open answer is required here.

- "What could you expect from 5G in mobility? (if 'other', please specify)". Here only few things are displayed so that the respondent can add anything he/she wants as "other" and express his/her expectations. Therefore, the possible answers are "Automated transportation (driverless cars, automated tramways, buses and trains…)", "Live information (parking possibilities, traffic jams, accidents…)", "Improved car-sharing" and "Other". In this latter answer, the respondent has the possibility to enter a short open answer.

- "What could you expect from 5G in healthcare? (If 'other', please specify)". The same kind of answer than for the previous question is displayed. Indeed, only a few possibilities are present: "Data transmission between doctors, hospitals, etc.", "More reliable telemedicine", "Better management of patients in hospitals", "Better connectivity in hospitals", "More usage of wearable devices (e.g. to track one's heartbeat, or to find the closest nurse in hospitals…)", "Other...".

- "What could you expect from 5G in housing? (If 'other', please specify)". In this question, the same kind of answer is available than for the two previous questions. Therefore, we encounter some possibilities of answers, as well as a "Other" possibility with a short open answer. The possibilities displayed are: "Remote visits (by making more effective Augmented Reality)", "Better response to the growing demand", "Better pricing", "Smart homes/buildings", and "Other".

The goal of this fourth section is to give an idea to the respondent of what 5G is while keeping a neutral tone in order to acknowledge the latter's expectations and needs. Open answers are possible in order for the respondent to have the freedom to answer whatever he/she wants and to avoid the bias.

Least, the fifth section is the identification of the respondent called "You are". Five questions are being asked in this part:

- "Your gender", with three different answers possible: "A man", "A woman", "Rather not say"
- "Your age"
- "Your occupation" with a listing of all socio-professional classes as possible answers
- "Where do you live?"
- "Your ZIP code"

3.2.3 Survey administration

To administrate the survey we are being asked to meet individuals that can represent our sample in order to ask them our questions.

This survey is about the new technology that is 5G, hence, it seemed necessary to administrate it to people that are the most likely to be able to answer to the present research sub-question, that is, people in the age range of twenty to sixty-four years old.

Therefore, the chosen model is the auto-administration of the questionnaire. Indeed, for online study, we are using the Internet to send the survey to potential respondents.

As a consequence, the survey has been administered via three distinct ways: first of all via social networks (i).

Indeed, Facebook and LinkedIn represented an important part of the administration of the survey "Smart Luxembourg".

The latter has also been shared on three distinct users' accounts and has been shared on "groups" linked to mobility, housing and healthcare such as:

- Luxembourg Housing, rooms, flats, apartments
- Mobility in transition
- Luxembourg real estate

Moreover, the survey has been shared on other types of groups on social networks such as expatriates groups, as well as students groups such as:

- University of Luxembourg students
- Français au Luxembourg
- Luxembourg Expats
- Expats de Lux
- Students@Lux

In addition, the survey has been sent on private messages via social networks and WhatsApp to people living in Luxembourg (ii).

Then, the questionnaire was sent by emails, (iii) explaining the goal of this survey and explaining why the people that received it were interesting to interview. The emails were sent with the hyperlink that would directly lead the person on the online survey.

By this auto-administrated mode, we could gather a total of a hundred and nine answers without any financial cost and allowed us to have visual support of the answers thanks to the schemes and other graphs that Google forms was constructing. Indeed, it is the platform on which the survey has been built. This in fact, enhanced the analysis of the results. This total of answers shows the external validity of the research by the fact that the minimum necessary answers required to get meaningful results of eighty-nine respondents has been exceeded.

In order to fill a gap between academic papers and what is really happening in Luxembourg's current challenges, interviews have been conducted.

The survey analysis method is explained in Appendix 6. The results gathered are available upon request.

4 FINDINGS AND DISCUSSION - HOW COULD 5G ENABLE LUXEMBOURG TO BECOME A SMART CITY?

The Grand-Duchy of Luxembourg, has a strategic position in Europe and is considered as a wealthy country in which it is good to work, which is one of the reasons its population knows an exponential growth. The corporate world of Luxembourg is considered as efficient and wealthy while the public sector faces some challenges to be tackled.

Although Luxembourg is a data nation and a quite innovative one, digitalization is considered late in the country in comparison with other European countries, and above all regarding the public sector.

Luxembourg is facing many challenges that have all one thing in common: the fact that the country is welcoming a big amount of new inhabitants every year. This has been confirmed by one of the interviewed experts: "*we encounter a general problem for those* [public] *sectors: the country is welcoming more and more new inhabitants at a fast pace. Maybe too fast for infrastructures e.g. roads, hospitals, housing*".

Even though Luxembourg is one of the smallest and one of the least-populous countries in the European Union, it faces a remarkable population growth rate of around two percent every year (Appendix 8). It is the largest population growth rate of Europe. This represents the biggest challenge Luxembourg is facing.

4.1. Focus on the public sector and its challenges

The public sector is constituted of the military, infrastructures, public transit, public education, healthcare etc. Its role is to provide services a non-payer cannot be excluded from which are basically services which benefit the whole society rather than the individual who uses the service.

Resulting from the defy of the growth of the population, three main sectors are facing bigger challenges than the others: mobility, healthcare and housing: "*We are fully aware of the issues Luxembourg has to address, the challenges that it is facing. Especially in housing and transportation, because of the size of the country*" stated one of the interviewees while another posited "*I think in Luxembourg the biggest pain points at the moment are in mobility and in housing*" and completed this thought by adding "*health is now a key challenge for any advanced economy*". Those pieces of information fill a gap as no prior academic literature exists regarding the current main challenges the country of Luxembourg is facing.

Furthermore, an important challenge for the Grand-Duchy would be to bring all the sectors together in order to share all the data and coordinate those strategies and act on the data-governance strategy and so-on. Therefore, the defy is about making the evolution of those specific sectors possible, but it is also about enhancing the citizens' lives.

In addition, three of the interviewees argued that it is essential for the country to aim to make itself a data-driven economy. Consequently, there is a link between the main objectives of the government; making the country as a data-driven economy and the objectives of the city to sustain its smart capabilities.

Accordingly to the territory's current situation and challenges regarding its public sector, technologies have to be aligned with the objectives. In this regard, we will further discuss how 5G technology could enable Luxembourg to tackle its challenges regarding mobility, housing and healthcare. Indeed, we could previously discuss that, according to Marabissi et al. (2019), new 5G macro-applications will make their appearances such as industrial automation, transportation, digitization of the living environment (e.g. with smart homes amongst others), public safety services, telepresence services (e.g. with VR and holograms) and other systems of a public utility such as healthcare.

4.2. Smart cities defined by experts (comparison with the literature)

Although academic literatures state that smart cities have specific components, we could argue this by the interviewed experts' definition that would rather characterize a smart city as a whole and in regard with its objectives. Indeed, one of the interviewees stated that "*A smart city is often associated directly with digital and technology but I think, to consider a city truly smart, one needs to consider the impact that it should create rather than what one would put in the city in terms of technology and so on. Thus, for me, to consider a city smart is to interest yourself in the impact that you have as a city on the society, the economy as well as the environment*". She could also add that a smart city should firstly assess the outputs i.e. "*the impact it wants to have on the society, environment and economy*" then assess the inputs such as the technology needed to set, the data and the skills the city would want to respectively collect and develop, the infrastructures it needs as well as the services it could provide. The three aspects economy, society and environment go along with Allwinkle & Cruickshank's (2011); Alves (2007); and Caragliu et al. (2011) that stated a smart city is a city that can sustain social, cultural, economic and environmental progress.

Moreover, in comparison with the literature, according to experts, a smart city "*is everything*" in the sense that, even though components of a smart city exist, it is much more of a project. Indeed, one should rather ask oneself "what impacts does my city want to make?" and think about the pain points of all end-users, than ask "what components do I want for my city to be smart?". Then, those analyzed pain points should be taken as a basis to define projects that are relevant for the city.

Therefore, a smart city could be defined as the combination of assets which mix innovative ecosystems, infrastructures and technological and data-analysis capabilities. It combines all of those in order to provide an environment which is appropriate for developing public, technological, and digital services for the benefits of the end-users of the city. In this regard, although academic literature state mostly that smart cities are citizens-centric, five of the interviewees argued that businesses are also considered as end-users of the city. Thus, the experts' point of view is more aligned with the European Commission's definition of a smart city than with the literature.

Thereafter, another gap has been filled during those interviews: the need to make the cooperation between private sectors actors and public sectors actors. Indeed, in order for some public sectors to become smarter, one of the main challenge is to be able to bring both private and public sectors together in order to make them cooperate by sharing all the data and coordinate the strategies of the city in order to act on the data-governance strategy.

4.3. The case of mobility

4.3.1. Current challenges in terms of mobility

Three of the interviewed experts of the public sector stated that mobility is an increasing issue in Luxembourg. They explained that the main issue in Luxembourg regarding mobility is the traffic which has been rated as "Very poor" by twenty-three people out of the one hundred and nine respondents. It was rated as "Below average" by twenty-six people and "Average" by thirty-five people in the survey (Figure 4). Another big issue, expressed by both the interviewees and the respondents of the survey are the parking possibilities.

Therefore, it seems that all those challenges come from a bigger problem which is the habits and mindset of the inhabitants. Indeed, most of them would rather use their own vehicle than car-sharing or use public transportation on a routine basis.

How would you rate each of those criteria?
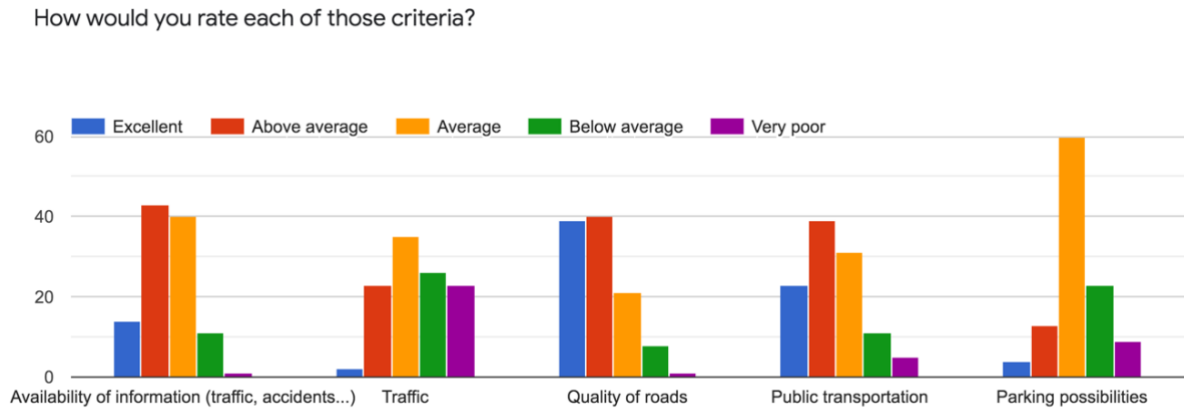
Figure 4. Current mobility situation

4.3.2. As-is situation versus to-be possibility

The current situation of the mobility in Luxembourg has been described as "*difficult*", "*poor*", "*dissatisfying*", "*rather bad*", "*disorganized*", "*unpleasant*" and even "*chaotic*" by most of the survey's participants at the open-ended question "How would you describe the overall mobility situation in Luxembourg?". Out of a hundred and nine respondents, only thirty-eight of them described the situation from "Ok" or "Mostly good but could be improved" to "Excellent" or "Very organized and reliable" for example. The seventy-one others had something to criticize which has been categorized into four main issues that are; the infrastructures and roadworks (i), the traffic-jams (ii), the public transportation (iii) and the parking possibilities (iv). Experts confirmed that the mindset of people in Luxembourg is part of the reason the country (and mainly Luxembourg-City) is very congested. Luxembourg has the highest car-usage in the world per person. They also affirmed that the infrastructures are no longer fit for purpose, as the country was not prepared to face the critical development of the needs of the growing population. For the same reason, parking represents a big challenge, above all in busy districts and in the city center of Luxembourg-City. The following table synthesizes the current mobility situation in Luxembourg and shows how it could be improved thanks to 5G.

Table 4. As-is situation compared to to-be possibility with 5G for the case of mobility

	As-is situation	To-be possibility
Traffic	Enormous problems of traffic jams.	Traffic management made available thanks to V2V and V2P possibilities. Pro-active traffic management system by knowing exactly how many vehicles are connected or are circulating in the city. By avoiding car-accidents thanks to URLLC, traffic jams can be avoided. Would also help with car-sharing and having algorithms in order to more easily calculate how one can get from a point to another, and to know whom to share a car with. Possibility of using self-driving cars that are made efficient thanks to 5G reliability and low-latency. "*It needs to be perfectly reliable at all times and data needs to be processed so fast that every millisecond matters to make the car react*" stated three of the interviewees.
Infrastructures	Road infrastructures no longer fit for purpose. Ongoing construction sites to improve the infrastructures but it takes time.	Better quality of roads thanks to trackers and live information and therefore better management of roadworks. Availability of live information.
Public transportation	Free public transportation within the entire country. Lack of punctuality of buses but good quality of buses. Rather bad quality of trains, and only one tramway line. Buses have their own lane on the roads.	Connected buses by getting online live information about the position of the public transports thanks to GPSs to track them.
Parking possibilities	Difficulties with parking possibilities. Expensive parking lots. Not enough parking spots.	Set up of applications for live parking possibilities and live mobility (with live information about accidents, traffic jams, roadworks, etc). Parking demand simulators enabled by vehicles' GPS and by sensors in parking lots and in the street.
Other	Few city bikes stations. Poor cycling paths in the city. Many regulations (Uber, electric scooters, etc).	Possibility to set up an application to track available bikes. Possibility to set more cycling paths thanks to the fact that traffic management would be better handled. Trackers on the roads and on bikes to send a signal when there is a problem on the cycling path e.g. holes, accidents etc.

Therefore, some solutions are enabled by 5G for those four main challenges, and there is a growing need to consider the data increases and the application benefits of those potential solutions, in a mode of mobility-as-a-service. This mode could be enabled with a new technological way of information that would contain all elements a person needs to know before going from a point A to a point B, such as the different possibilities offered at the moment (car, car-sharing, public transportation, city-bike etc.), road conditions, potential roadworks, the live traffic situation, the estimation of the journey's time and once at point B, the parking possibilities. Therefore, the data creates a new way of considering the rationality of actors.

Consequently, the main challenge is to create and structure this data in order to be able to make something useful out of it.

4.4. The case of housing

One of the objectives of smart cities is the global management of resources, therefore, the construction of smart houses becomes a necessity for cities to be intelligent according to Elariane & Dubé (2019). Home automation, the use of sensors and the connections M2M, M2P and P2P are applications we can find in a smart house or a smart building. One of the main objectives of smart cities and smart houses is sustainability.

4.4.1. Current challenges in terms of housing

Because of the remarkable growth of the population, the demand is very and unusually high, and a lot higher than the offer. The demand is so higher than the offer, that, consequently, everything that comes to the market is sold, no matter the price or the condition. This defy is thriving the prices up, and creates an urgency on the transaction, so people who are looking for a place do not have the possibility to do it in a comfortable way.

Every year, Luxembourg is facing an inflation in around six percent in terms of housing pricing, while the global inflation for this sector is between two and three percent a year. The most critical problem is that this inflation comes from the private sector, as the real estate is not in line with the needs of the population and that expends the increase in pricing. An interviewee stated that "*over a mid/long-term period, there is a discrepancy which is not manageable in terms of social welfare and of social policy; our ability to align the needs or the new infrastructures with the needs of a growing population*".

Most of the respondents to the survey are aligned with this. Indeed, to the open-ended question "How would you describe the housing situation in Luxembourg", ninety-six of the respondents described it as *"too expensive", "exaggerated prices", "overpriced", "difficult to afford"*, and so-on.

4.4.2. As-is situation compared to to-be possibility

While literature only talks about smart houses and the management of the resources (such as water, waste, etc.), it does not argue the case of housing.

At the question "What could you expect from 5G in housing?", forty-five respondents are expecting 5G could enhance remote visits and seventy-one expect 5G to make homes and buildings would be smarter.

Table 5. As-is situation versus to-be possibility with 5G for the case of housing

As-in situation	To-be possibility
Luxembourg has good network infrastructures which make 4G speeds faster than Wi-Fi. The housing industry is very low tech at the moment in the country. Hardly manageable constant growth of demand and huge inflation of prices.	5G could replace Wi-Fi and is an enabler of many use cases at home such as cloud gaming, a better video experience with faster downloads of movies as well as the development of connected items. 5G enhances smart houses and smart buildings with sensors and home automation. Smart housing could be made possible with the use of AR/VR for remote visits. It could potentially provide a solution for the demand-offer problem.

Unfortunately, as the biggest challenge for Luxembourg is the high demand, the main first defy would be to build more buildings. However, this is not made possible by 5G, even if the latter could enable those buildings and infrastructures to be smarter. Still, 5G could make smoother the housing industry by enabling remote visits with technologies such as AR and VR.

4.5. The case of healthcare

4.5.2. Current challenges in terms of healthcare

As an interviewee posited, healthcare is such an important topic that it should always be considered a main focus point. Regarding this sector, the Grand-Duchy is facing a main challenge in the fact that hospitals are crowded and are always being asked to be more profitable. Also, the constant growth of the population is an issue as, twenty years ago,

the country had four hospitals. Today, in 2020, it still has only four of them despite the considerable acceleration of the demographic development. An interviewee stated "*we had four hospitals twenty years ago, and still have four of them today even if the growth of the population was around twenty to twenty-five percent over the last ten to fifteen years*". The hospitals start working as "daily-ones" in order to avoid the crowds and to make profit: "*the patient goes back home the same day he came in*". "*Most of the time, the patient has to come back to the hospital the day after for a check-up consultation to verify everything went well*".

Another challenge the country is facing regards the availability of specialists. Indeed, many respondents to the survey argued that there is a lack of specialists, which leads to a long waiting time in order to have an appointment (several months up to a year).

Nevertheless, despite those challenges, forty-five respondents rated their overall healthcare experience in Luxembourg as a four on a scale from zero (being "very poor") to five (being "excellent"), while only two respondents rated it as "very poor" (Figure 5).

How would you rate your overall healthcare experience in Luxembourg?
109 réponses
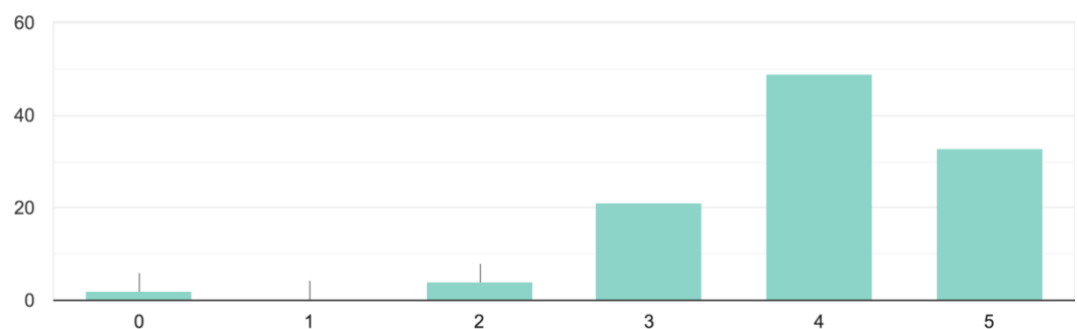
Figure 5. Rating of the healthcare experience of the inhabitants

Another challenge noted by both interviewees and respondents of the survey are the lack of data transmission between doctors, hospitals and specialists.

4.5.3. As-is situation versus to-be possibility

As a result of the main challenges healthcare is facing in Luxembourg, three categories of defies have been identified: telemedicine, situation in the hospitals, and data-transmission between medical actors. This has been confirmed by the inhabitants of Luxembourg who replied to the survey (Figure 6). Sixty-three respondents expect 5G

could enable an enhanced data transmission between the different medical actors. Fifty-one wish the tele-medicine would be more reliable. Fifty-nine expect a better management of patients in hospitals. Sixty-one citizens expect a better connectivity in hospitals and sixty-three wish 5G could enable more usage of wearable devices.

Figure 6. Inhabitants' expectations regarding 5G in healthcare

The as-is situation is being analyzed and compared to a potential future of healthcare with 5G in Table 6.

Table 6. As-is situation compared to to-be possibility for the case of healthcare

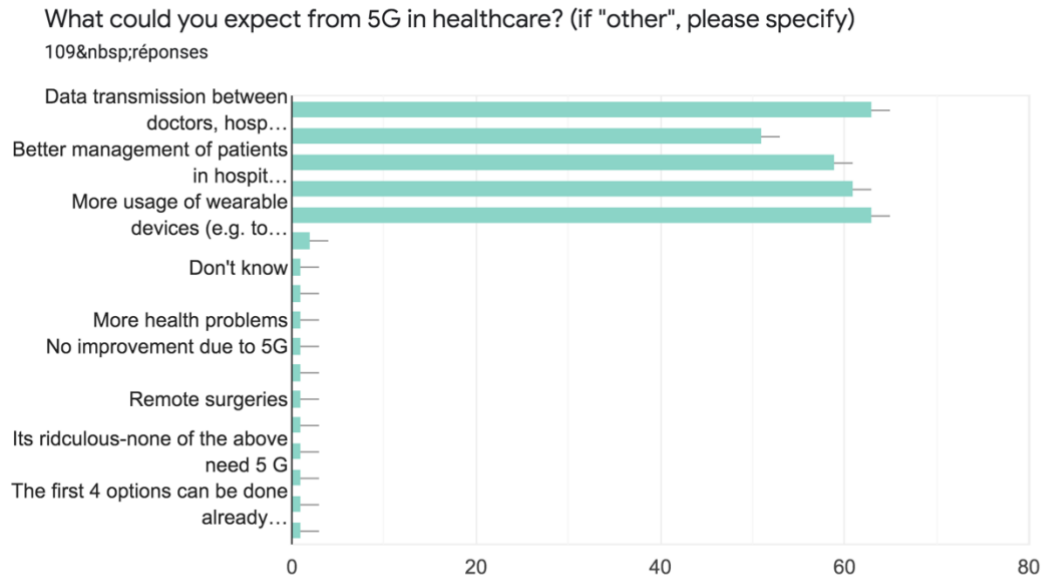| As-is situation	To-be possibility
Telemedicine used by phone or video calls for small no important cases.	5G is an enabler of enhanced telemedicine and live-video consultations thanks to URLLC. 5G will be faster, provide a better connection, and will be probably easier to manage compared to setup such as Wi-Fi that need to be configured. Telemedicine will also be enabled by wearables: some devices that are 5G compatible or health devices could be used to measure one's sugar blood, heartbeat, etc. Therefore, one would need to have ongoing monitoring of some health parameter, then 5G will help healthcare system to be much more efficient in following up some patients because it will be everywhere. This would also have an impact on transportation because less trips would be needed.
Crowded **hospitals** working as "daily-hospitals" asking for the patient to come back the day after to have a check-up. Hospitals are also too big which makes the findings of machines and staff difficult. Bad connectivity in hospitals which leads to slow programmes for the medical staff and bad Internet connectivity in the rooms. There are only four hospitals in the country, which makes it difficult for people to go to one of them in case of an emergency.	An enhanced telemedicine could be the solution to decongest hospitals. Remote-surgery is made possible with 5G. 5G would be a good alternative to Wi-Fi as the latter has some issues in hospitals due to the fact they are big. 5G would avoid black spots and provide consistent coverage in all the different parts of the hospitals. 5G would provide additional services through connecting medical devices but also through providing services to the patient. E.g. in the rooms, patients would be able to stream videos etc. Inside the hospital, everything that allows communication can be enhanced with 5G such as video/radio communication between patients and doctors or nurses. The fact of having the possibility to videocall with the patient who would probably have a tablet next to their bed can create another routine and enable an easier work to the staff. So it could have a real impact on the well-being of the staff that would not have to lose too much time due to the considerable size of the hospitals. Tracking materials inside the hospital is enabled by 5G such as equipment, machine, small materials. Indeed, as very expensive they are shared so one cannot have some at every floor. Therefore, 5G would make easier the finding of those materials; the tracking-mechanism would be based on IOT to be able to know the location of the machines as well as who is using it at the moment and possibly for how long.
Poor **data transmission** between medical actors.	Centralizing health data is a challenge that can be better achieved with 5G. Every hospital, every doctor, every laboratory has some patient and health data. Thus, there is a need to gather this data on an anonymized formulate. Therefore, putting in place this data lake would enhance the data transmission between medical actors. Creating an application or a shared website for all the hospitals would easily allow the access to the patients' records – i.e. scan, blood tests, consultations at the specialists', current medication. Also for the generalist as well as for the patient, the CNS, pharmacy, etc. However, there could be an issue of having to coordinate a lot of different actors who would need to cooperate.

Some challenges could raise regarding this to-be potentiality of a future smart healthcare, such as security and cost concerns as well as regulations concerns. Indeed, this is a sector in which there is a lot of laws and regulations. Also, data protection could represent a real challenge for a smarter healthcare.

In addition, one of the interviewees stated that hospitals would need to look closely at the impact of 5G, not only on the people themselves but also over medical devices. Therefore, some acceptance tests would need to be done to ensure that 5G is not distorting signals between the different medical devices that are already there.

4.6. Framework and discussion

The interviews conducted with the experts coupled with an existing strategic plan from the European Commission enabled us to establish the framework of a strategic plan for the implementation of a smart city strategy.

4.6.2. Framework

The European Commission during its Intelligent Cities Challenge (ICC) webinars provided a basic smart city implementation plan in four steps (European Commission, 2020) (Appendix 7):

- Assess the city's performance and needs
- Create a vision and refine the strategy
- Create a roadmap for the project to achieve the vision
- Implement the project and see results
- Measure and build on your success

This strategic plan coupled with the smart cities experts interviews enabled us to build a framework in order to help cities becoming smarter (Figure 7).

Areas	Define areas (level of the cities that need to be enhanced. E.g. the whole city or one neighbourhood. Smart city is very transversal so one needs to have defined areas-speak, mobility, and infrastructures to collaborate together to get something that really makes sense.
Challenges	Define the main challenges for this area, and assess a maximum of four needs. What impact do you want to make?
Outputs	Define the outputs. What outputs do you want to create? (e.g. smarter housing, mobility, manufactures, healthcare, improved logistics etc.) Think about the pain points (of the citizens and companies - as they both are end-users of a city), then take those pain points as a basis to define projects that are relevant. Think about it in terms of society, environment and economy matters.
Vision and strategy	Create a vision a build a strategy.
Inputs	Define the inputs. What inputs do you want to be used in terms of skills, technologies and data?
Roadmap	Create a roadmap for the project. How to achieve your vision?
Implementation	Implement the project and analyze its results. What are the outcomes of your project? Did you achieve your objective?
KPIs	Build Key Performance Indicators for successful achievements. Re-start from the first step for unsuccessful points.

Figure 7. Framework built based on experts' interviews and European Commission's framework

Therefore, this framework works as an eight-steps-guide to help cities that aim to become smart or smarter.

4.6.3. Discussion

Luxembourg has many advantages and opportunities for its way to become a smart city such as the fact that the country has many data houses. It was mentioned by three of the interviewees. One stated *"Luxembourg has the highest proportion of data-centers in the world as a country regarding its size. Therefore, a lot of infrastructures are in place when it comes to hosting data and the connectivity is very strong. The country is also one of the firsts when it comes to speed"*. Therefore, the challenge would be to analyze the data efficiently in order to get useful outcomes out of it. Another expert mentioned that the Grand-Duchy can be identified as a data and innovative nation.

Thereafter, the European Institution is based in Luxembourg and represents a key driver for innovation, digitalization, an asset in terms of human capabilities and expertise for the Grand-Duchy. The country also hosts a *"Centre des technonologies de*

l'information et de l'Etat" which represents an informative organ of the State and which is another important driver of the digital transformation of the country. With high expertise and with highly top-notched experts in informatics, as well as in new technology and engineers, the CTIE represents a good actor by being a resource in its help transforming the country, digitalizing it and accelerating the innovation.

According to the interviewees, 5G, by its fast internet connection would enable Luxembourg to develop new applications for connecting key items of the city/country. They also consider Luxembourg as very strong at having the mindset and the vision to get to the smart stage, as it is good by acknowledging the interests of the end-users (i.e. the companies and the citizens).

Nevertheless, the main challenge would be to protect individuals' data and privacy.

Furthermore, Luxembourg has many advantages and opportunities for its way to adopt 5G such as its great connectivity and network infrastructures. Indeed, if one has 5G hotspots but no fiber neither a good connectivity and networks, then 5G is considered useless. The Grand-Duchy is considered by one of the interviewees as a country that has a lot of benefits to deploy 5G in comparison with other States. Indeed, it is a very small country with one main region which covers around eighty percent of the population, thus, this would facilitate the implantation of 5G. The main benefit of the country in deploying this technology is to help the country moving forward in terms of digitalization and to develop new solutions. An expert stated that Luxembourg could even potentially become a life-laboratory in which companies would be able to test new 5G applications for mobility or healthcare for example, because 5G can be made available in a rather short timeframe for a broad range of the population due to its smallness.

5G is considered as one of the inputs as it does not have a value in itself, but it is an infrastructure that, once put in place, enables the application of other vertical services and data processing a lot faster and a lot more efficiently, with added reliability in comparison with its predecessor. Therefore, as it is faster, then the investments made for its deployment and its adoption are also made at a faster speed.

Furthermore, Luxembourg, in a rather long-term could have the opportunity to implement a platform on which all the public administrations share the data and all the data of the citizens is present on one and only platform. This is the case of e-Estonia that created it for, e.g. voting, paying taxes, adding any type of document to the administration, but also for healthcare, with the possibility to have access to e-prescriptions, as well as for parking strategy and road administration that are being

managed with the data collected with the sensors. Everything can be done online; even the ministers can do e-meetings. According to one of the experts, even the elder people have accepted this way of doing.

Therefore, the biggest challenge for Luxembourg is to gather the data in an only platform, although it is nowadays very siloed.

While looking at Luxembourg's inhabitants' mindset, they seem mostly ready for the implementation of 5G in the public sector, as the majority (thirty percent) voted five (being "Strongly agree") at the question "Do you think 5G would benefit the public sector?" (Figure 8)

Do you think 5G would benefit the public sector?
109 réponses
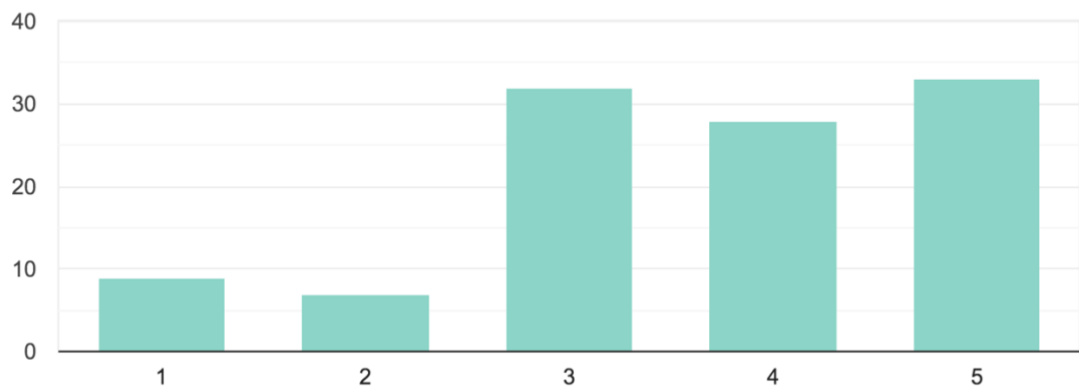
Figure 8. Luxembourg's inhabitants thoughts about the benefits of 5G in the public sector

Also, it seems that Luxembourg's citizens are somehow impatient to have 5G. Indeed, to the question "How soon do you think 5G should be used in Luxembourg for each sector?", a big majority of respondents answered "As soon as it is available" for each of the three sectors (Figure 9). Their readiness is bigger for mobility than for healthcare and housing: respectively fifty-seven people, forty-six and forty-one respondents answered "As soon as it is available".

How soon do you think 5G should be used in Luxembourg in those three sectors?
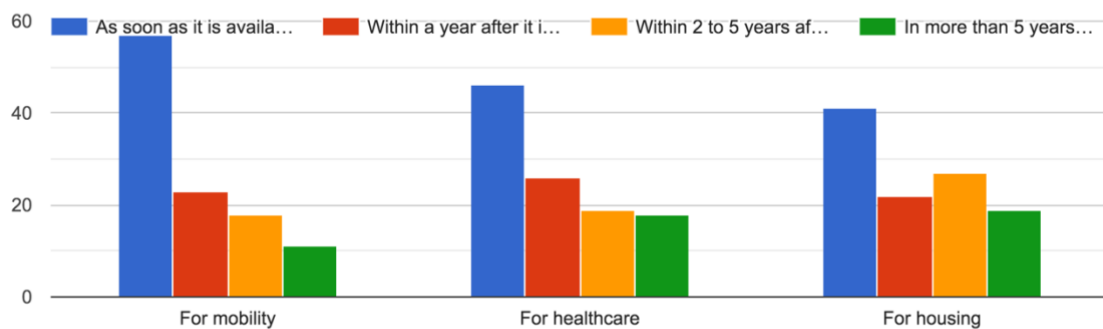
Figure 9. Readiness of inhabitants to see the three sectors evolve through 5G

Moreover, another sign of the acceptation of citizens with the idea of 5G implementation is represented by their fears that are mostly moderate to low (Figure 10). Indeed, fifty-five percent voted "Not at all" for health issues fears against eighteen who voted "Extremely". Sixty-two percent voted "Not at all" and nine percent "Extremely" for reliability issues. However, data protection issues are extremely feared by thirty-five percent of the respondents while twenty-three percent do not fear this matter at all. The majority of the population (forty-five percent) have moderate fears regarding environmental concerns.

Would you fear:
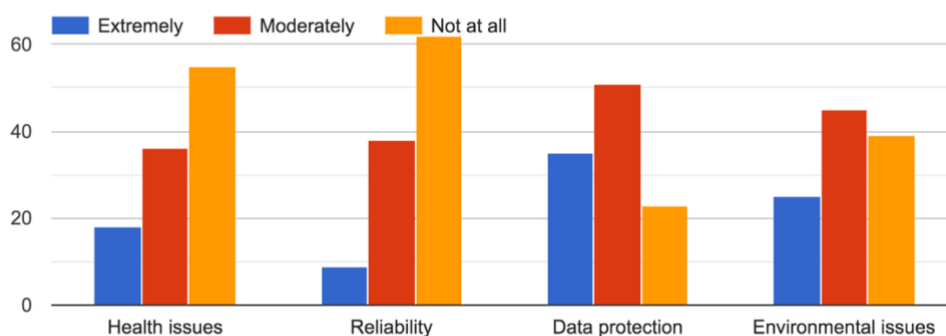
Figure 10. Fears of Luxembourg's residents regarding 5G

However, to the open-ended question "Would you have other fears regarding 5G?", some of the respondents added some thoughts such as the fear it "*will increase individualism,*

"political stability, "misinformation" and "misinformation spreading". Although, an important majority of respondents replied they did not have any other fear, and some added they thought Luxembourg needs "*to start using this new technology as soon as possible*" and that "*the benefits will be considerable*".

In addition, this research paper filled the gap of Luxembourg's situation by analyzing the wants, needs and expectation of the Grand-Duchy's inhabitants regarding the future of their country. The latter are expecting from the country to evolve towards a smarter one and wish the three discussed sectors will improve. They expect from 5G to enable them to get better and smoother.

This research is reliable by the fact that the results can be reproduced when the research is repeated under the same conditions. Even though we will know more about 5G in a few years, it has already been discussed that the technology could improve the public sectors as long as a strategy has been set for the evolution of the city towards a smart city. For this matter, a framework has been provided. Also, an internal consistence has been achieved. Indeed, both the questionnaire and the interviews can be randomly split into two halves and there would be a strong correlation between the two sets of results as the same results are gathered from different parts of both the survey and of the interviews. This research paper also provides a criterion validity as it has been shown by the desk research that 5G could enhance the sectors of mobility, healthcare and housing. This argument was confirmed by experts and finally agreed by the respondents. This provides both internal and external validity. Besides, we can argue that content validity has been proved by the fact that all aspects of both the healthcare and the mobility sectors have been covered.

5 DRAWBACKS OF 5G AND CHALLENGES FOR SMART CITIES

Although 5G technology is very recent and is still being researched, drawbacks and challenges of the fifth-generation wireless communication technology start to arise.

5.1 Drawbacks of 5G

Even though health issues seem not to be very feared by Luxembourg's inhabitants, it is one of the most argued concerns in the papers. Indeed, some countries such as Belgium had to postpone the implementation of 5G for health matters due to concerns about the waves. Besides, one of the interviewee argued this concern by saying "*there is still a lot of discussion and mixed messages concerning 5G, saying it could be an additional risk for the health of the people because today there's no inner study that has been done. So everyone is giving his own comment about the risks of 5G, and, because of that, it creates confusion and it is difficult for the operator to move forward because they do not know themselves if there is any risk. If there are any risk scientifically proven, what could be the impact and therefore, they could expose themselves to penalties or to cold cases where maybe 5G has had some negative impact on someone's health*".

In addition, 5G implementation comes at a cost: it requires a considerable investment in network infrastructures (Deloitte, 2018). The technology could also represent a threat to the current business model of wireless service providers (WSPs). Indeed, it enables multiple types of networks to be connected together, and potentially from different WSPs. Consequently, it can separate a critical linkage for telecommunications organizations: the network and the consumers' end devices.

Another drawback of 5G for certain sectors is the critical presence of many laws and regulations. It is the case of healthcare for example, and it could represent an issue for data transmission between the different actors.

Thereafter, two of the experts interviewed stated that "*the disadvantage* [of 5G] *is that, like for any new technology, one will need to wait a certain time after it is completely deployed in different countries*" and that "*pockets of services may be developed in big cities but not is all regions which means that, for example for the car that needs to be connected, sometimes one may not have full coverage which means that the services may not be fully available. So one needs to wait a few years or maybe a few months in order to have a consistent service level. Because of that, this represents a challenge for the*

service provider because it is not easy for them to convince customers if the service is only available today in 20% of the region".

Moreover, an important disadvantage of 5G is the lack of compatibility with older devices. Thus, the users would need new specific devices 5g-compatible. Similarly, an expert argued that "*it* [5G] *will require also significant investment on the side of the end-user. In fact, one won't be able to use the smartphone that one have today and one will need to get a grade and get a 5G handset. There are only few today; there are only 2 brands providing 5G handset, meaning that the price is very high because there is no competition. So again, in addition to the coverage, one also increase the first level of entry-point because one would need to have a specific device. Which is also an obstacle for some organizations and clients".*

5.2   Challenges of 5G for its implementation in Luxembourg

According to Nilan et al. (2019), there are a few challenges 5G is or will be facing such as: the amount of supportive devices, the data volumes, the lower cost with higher capacity, the new air interface as well as the speed of the devices on which 5G is being used.

In addition, Nystrom et al. (2019) state in their research paper that, as 5G is still being researched as its implementation started early 2019 in the world and is thus pretty recent, we are still facing some uncertainties. Indeed, we are still uncertain regarding the shaping of the market as well as the emerging ecosystem. We could then wonder what would be the actors' roles or what would be the ICTs chosen in distinct environments. Value could be created for different stakeholders, but its cost-benefit analysis as well as their role are still unclear.

Another challenge 5G is facing is its place by potentially replacing Wi-Fi and being the new generation after 4G. Indeed, two of the experts stated that "*5G will allow to have a much more consistent and uniform way to provide the services. There won't be dependency on some Wi-Fi setup or routers*". By contrast, one could argue that 4G is already sufficient for so many use cases, so some people could ask themselves "Why would we need 5G while we are already happy with 4G and/or Wi-Fi?". Consequently, the mindset of people represents a real challenge for 5G's implementation. Collectives such as "Stop 5G" in Luxembourg could represent barriers to the implementation of the technology. Also, interviewees could argue: the trust of citizens represents a defy for 5G; *do they really trust the lot of different actors to give them access to their data?* [with

regard to data transmission]". In addition, *"the habits of the actors is a big challenge e.g. one can use sensors to detect liabilities with the feet. Some doctors in Luxembourg were reluctant to use this kind of technology. It could facilitate online consultations but some doctors are not willing to change or to advance to new technologies. Therefore they do not really trust technologies as much as they do with other old school manual techniques. Maybe they feel that those sensors will not give a hundred percent good answers".* Along with the mindset challenge, the fears of the inhabitants are challenging for the setup of the technology (Figure 10). This defy comes up with difficulties for certain sectors such as mobility. This might be difficult to put such projects in place due to this strong psychology and the reluctance to change: "*of course now it is a bit early so the ideas need to be implemented and this is sometimes slower than in other countries. The implementation is a bit more of a challenge to get everyone to collaborate".* Besides, data protection represents one of the biggest fears of the inhabitants. Therefore, this and privacy aspect represent other challenges, as personal data is often involved.

Another expert interviewed stated that "*the cost is not only economic but comes also from a sustainability point of view. For example, the hosting of data is not good for our planet. Thus, the cost/benefits analysis is not so clear at this stage*".

A separate defy for 5G would be not thinking in silos. Indeed, as mentioned before in Chapter Six, silos have to be defined before going on with a project of smart city; "*smart city is very transversal so one needs to have defined areas-speak, mobility, and infrastructures to collaborate together to get something that really makes sense. At the city level it is often really working in silos. I know that there is an awareness that it needs to change* [in Luxembourg] *but it is not the case yet. Therefore, I think that silo-thinking and not being used to really collaborate with different stakeholders to solve one problem is one of the main challenges generally to make a smart city vision comes true".*

6   LIMITATIONS OF THE PAPER

6.1   Limitations in the research method

6.1.1   Limitations of the survey

The survey that has been built has a few limitations such as the lack of possibilities at the question "Where do you live?". The possibility to answer the name of another city has not been provided. However, as the study is made for the whole country rather than just for Luxembourg city, it does not have any impact on the results. Also, it was not needed to ask both "Where do you live?" and "Your ZIP code". The latter has been asked as we thought it could be interesting at first to know where exactly people live rather than just answering "In the suburbs", or "In the countryside". Nevertheless, this question seems useless as there is no specific differences analyzed between people living in Luxembourg city and people living outside of the city.

Moreover, it would have been interesting to share the questionnaire on healthcare-related groups on social medias. Indeed, the latter has been shared on mobility groups as well as on housing groups, but no healthcare groups have been found. This might have biased a bit the answers.

Also, a high proportion of students constituted the pool of respondents (twenty four percent) so we can assume not all of them have a car or financial means, which could have biased the survey (e.g. for the questions of the kind of transportation and 5G and housing). Although, it seems that the results have been balanced since the other part of the respondents has another kind of activity (Figure 11). The fact that many different people from different occupations replied to the survey enhances the validity of the research.
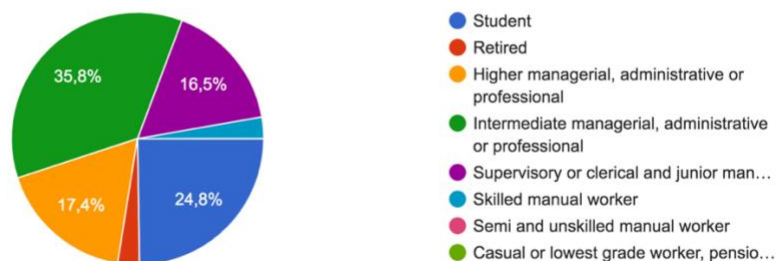
Figure 11. Occupation of the respondents

6.1.2 Limitations of the interviews

Being able to interview more experts about the topic as well as telecom companies would have been interesting in order to gain a better understanding of the technology as well as have more insights about its possibilities and drawbacks.

In addition, being able to have the possibility to interview a person working at the city council or even at the government could have been very interesting and would have brought this research paper some more interesting outcomes about Luxembourg's current challenges for the city as well as for the country.

6.2   Limitations of the findings

It has been difficult to assess how could 5G tackle the challenge of the housing situation in Luxembourg. Indeed, the main challenge being the high growth of the population and the increasing demand being superior than the offer, we did not find any solution 5G could provide. Therefore, we can assume that the content validity is not fully completed regarding the housing sector in this paper.

7 CONCLUSION AND RECOMMENDATIONS FOR FURTHER RESEARCH

7.1 Conclusion and predictions

5G is a set of technologies (Deloitte. 2018) and represents the fifth-generation of wireless communication network.

The main differences between 5G and its predecessor the fourth-generation are the prior's capacity, reliability, low latency, large bandwidth and efficiency (Koot, Soonius & KPMG, 2018).

A city is considered smart as long as it follows a strategic plan and aims to tackle its main challenges. A smart city can be everything and has lots of components, so that it does not have an universal definition, but should rather be thought as a project.

However, it is essential to mention that, for an efficient smart city strategy implementation, it is imperative for the city to establish a plan before implementation by starting to assess the level it wants to enhance (district level, city level or even country level). Then, it has to make sure of the challenges the city is facing and needed to be tackled. Once it has been completed, the city should identify the impacts it wants to make (and therefore, the outputs it wants to create) in terms of society, environment and economy. Afterwards, it should build a vision and refine its strategy and identify the inputs (in terms of technologies, skills and data). Then, it can finally create a roadmap of the project in order to achieve its vision before implementing it and analyzing the results.

5G can make cities smarter thanks to its five main characteristics. Indeed, it could enable smart mobility, smart healthcare as well as smart housing by enabling, driverless cars, remote-surgery, enhanced telemedicine or remote visits for housing for example. To this end, we can state that 5G could help cities to become smart cities as long as the communes are being aligned with the technology and are following a smart city implementation framework.

The main challenge Luxembourg's public sector is currently facing is the exponential growth of its population. This defy brings other challenges to specific sectors and more especially for healthcare, mobility and housing in the Grand-Duchy. Luxembourg is considered as a data-nation and could therefore benefit of the implementation of 5G in its public sector. Although this technology has also drawbacks, such as the fact 5G-enabled devices will be needed, it seems that Luxembourg's inhabitants are ready for the

implementation of the technology and has diverse expectations from it in terms of housing, healthcare and mobility. Indeed, it seems that the main challenges for 5G deployment are mostly based on fears such as data-protection concerns, the potentiality of health issues or environmental issues. These matters are still being studied so it is difficult to position these potential impacts as drawbacks per-se.

For the implementation of 5G, it seems essential for Luxembourg to be able to align both public and private sectors in order to make the data-transmission efficient enough to get something out of the deployment of 5G. Another challenge the country could face is the mindset of the end-users that could represent a barrier for the implementation of the technologies in some sectors such as healthcare, in which the actors could be resilient at the use of e.g. remote surgery.

5G is supposed to start its deployment on the first of July 2020 in the Grand-Duchy. The predictions for 5G are mostly positive thanks to the gigabit speeds expected, and its adoption is forecast to rapidly accelerate in several market as well as to enable use cases in vertical services. In the USA, Rivett, & Holt, (2019) stated that 5G could have the possibility to unleash $4.3 trillion in worldwide value through many use cases such as, amongst others mobility, healthcare and manufacturing. Therefore, one can ask oneself what value will be unlocked in Luxembourg? Will people accept 5G deployments? What new use cases will emerge? Will 5G benefit from 5G in a rather short or long timeframe? What will be the next emerging trends of 2030? Will Luxembourg be considered a smart city in the next decade? Are we evolving towards the suppression of Wi-Fi for the benefit of 5G? How will the mindset evolve in Luxembourg?

Finally, as Dean Kamen stated "*Every once in a while, a new technology, an old problem, and a big idea turn into an innovation*", we could think as 5G as the "*new technology*" and the challenges in the healthcare, mobility and housing sectors as the "*old problem[s]*", therefore we could argue, what are going to be the innovations?

7.2   Recommendations for further research

As discussed in Chapter Seven, this research paper has some limitations due to time and means constraints. Therefore, we could make a few recommendations for potential future researches.

First of all, being in contact with the government could benefit further research on the topic in order to have access to current numbers, rates, percentages, etc. in terms of housing, mobility and healthcare. It could also be a additional resource for the research

to have access to their smart city maturity framework and to evaluate the country's actual level of smartness and readiness for such projects.

Furthermore, we can recommend for further research to make another focus on private sectors, i.e. businesses as they are also considered end-users of the city. It could be interesting to acknowledge their expectations regarding the future of Luxembourg, as well as their readiness and expectations towards the use of 5G.

Being in contact with telecom companies in order to know their own mindset about the implementation of 5G in the country could provide additional insight to the study.

Potential other research can be made on the impacts and benefits 5G could have on other sectors such as manufacturing.

Thereafter, the use case of countries that implemented 5G could add additional insights regarding both benefits and drawbacks of 5G. However, this might be analyzable in a few years only, once the cost-benefit results will be clearer.

To conclude, we recommend for further research to look further at how could 5G help Luxembourg tackle the increasing demand in terms of housing.

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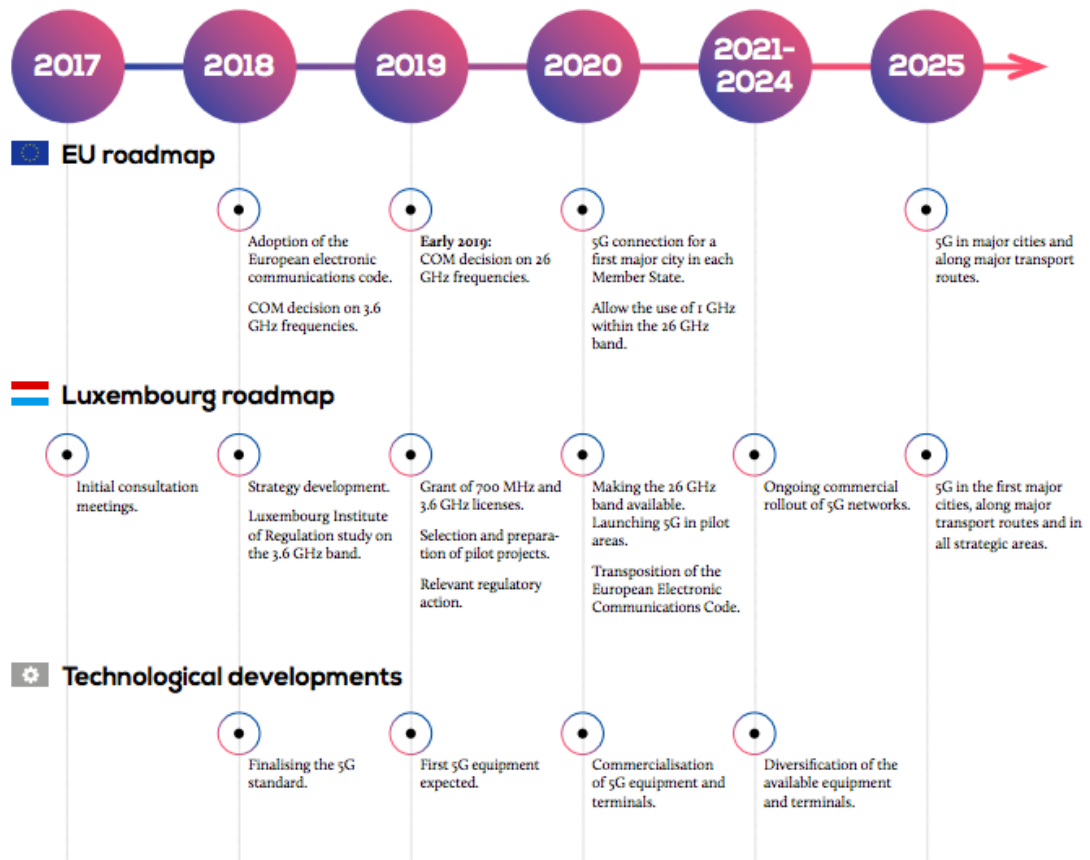
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APPENDICES

Appendix 1. 5G strategy roadmap in Luxembourg

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Appendix 2. Interview guide public sector and smart cities

First of all I would like to thank you for your time and for your help.

In order to set the background, I am a Master student in Management of IT. I have to write a thesis for which I chose the following topic: "Luxembourg's evolution from city to smart city with 5G".

For this matter, I am focusing on the public sector and more especially on housing, healthcare, and transportation sectors.

Therefore, my goal is to know how 5G could enhance those sectors in Luxembourg, and be useful for them to overcome the challenges the city/country is facing. In my questions you will find 3 main divisions:

- Smart city
- Luxembourg
- 5G

Please, be as specific as you can, and give as many details as you wish.

Luxembourg-related questions:

1. Are you aware of the biggest challenges of Luxembourg's public sector?
2. Therefore, what are the biggest challenges for each of these sectors?
3. Could you say that Luxembourg is a smart city?
   Why?
4. How could Luxembourg become a smart city? And more especially, how could Luxembourg become a smart city in terms of the sectors you mentioned?

Smart city-related questions:

5. According to you, what makes a city smart?

I have found that a smart city, according to research papers has several components;

Table 3
Comparison between academic research and practical tools

Component element	Academic literature	Innovation cities™ (IC)	European Mid-sized cities (EMC)	Digital Cities survey (DCS)	Global City indicators (GCI)	Habitat Urban indicators (HUI)	IBM's assessment model
Public services							
Transportation	✓	✓	✓	✓		✓	✓
Safety	✓	✓	✓	✓			✓
Housing		✓	✓			✓	✓
Health	✓	✓	✓	✓	✓		✓
Social services	✓				✓	✓	
Water		✓			✓	✓	✓
Energy, electricity		✓		✓	✓		✓
Solid waste		✓			✓		
Shelter					✓	✓	
Emergency services	✓			✓	✓	✓	
Food		✓					
Culture, tourism, recreation	✓	✓	✓	✓	✓		
City administration and management							
E-government	✓		✓	✓			✓
Performance management	✓						
Funding	✓	✓		✓			
Staffing	✓	✓		✓	✓		
Leadership	✓	✓		✓			
Vision	✓	✓		✓			
Policy instruments	✓	✓		✓			
Policy learning	✓	✓					
Institutions							
Institutional type	✓						
Intergovernmental agreements	✓						
Rule of law	✓	✓					
Governance, engagement, and collaboration							
E-governance	✓			✓			
Stakeholder, citizen, community engagement	✓	✓	✓	✓	✓	✓	
Network, partnership, and collaboration	✓		✓	✓		✓	
Human capital and creativity							
Creative class	✓		✓				
Social infrastructure	✓		✓			✓	
Education	✓	✓	✓				
Skilled workforce	✓	✓	✓	✓			
Knowledge economy and pro-business environment							
Knowledge economy	✓		✓				
Creative industry and entrepreneurship	✓	✓	✓			✓	
High-tech industry	✓	✓	✓	✓			
Business environment	✓	✓	✓	✓	✓	✓	✓

Table 3, continued

Component element	Academic literature	Innovation cities™ (IC)	European Mid-sized cities (EMC)	Digital Cities survey (DCS)	Global City indicators (GCI)	Habitat Urban indicators (HUI)	IBM's assessment model
Built environment and city infrastructure							
Environmental and economic sustainability	✓						
Functional management	✓	✓					
Attractiveness of built infrastructure	✓	✓					
Natural environment and ecological sustainability							
Ecological sustainability	✓	✓	✓	✓	✓	✓	
Monitoring system	✓	✓	✓	✓	✓	✓	
Pollution		✓	✓	✓	✓	✓	
Attractive natural condition			✓				
ICT and other technologies							
Broadband, wireless	✓	✓	✓	✓	✓		✓
Virtual technologies	✓	✓		✓			✓
Ubiquitous accessibility	✓	✓		✓			✓
Computing network	✓	✓		✓			✓
Service-oriented architecture	✓			✓			
Data and information							
Data management	✓			✓			
Information processing	✓			✓			
Information sharing	✓			✓			

What do you think about it?

6. Would you add/delete some components from it?

7. In general, according to you, what are the biggest projects/challenges for a smart city?

8. In general, for a city to be smart, what are the biggest challenges in terms of:

   - Health

   - Transportation

   - Housing

5G-related questions:

9. Do you have some knowledge about 5G?

   If yes, How do you think it could enable Luxembourg to become a smart city?

   If no: 5G is the fifth generation of wireless technology, advances mobile technology in speed, number of permissible connections, latency, capacity, and reliability. It can improve communication between people, but also enable people to interact with the growing ecosystem of connected machines around them. The reality is that 5G will be the catalyst to significant long-term changes in the way people communicate, and what gets communicated.

   5G can deliver private, secure, and reliable communications, massive M2M (Machine-to-Machine) and IoT communications, real-time data transmission, and enhanced tracking of assets.

10. According to that, do you have an idea of what could be the benefits for the public sector in Luxembourg with the deployment of 5G? Above all in terms of the three sectors previously mentioned.

11. How do you think 5G would impact/challenge and benefit the public sector?

12. Is there anything else you would like to add?

Many thanks for your participation!

Appendix 3. Interview guide 5G

First of all I would like to thank you for your time and for your help.

In order to set the background, I am a Master student in Management of IT. I have to write a thesis for which I chose the following topic: "Luxembourg's evolution from city to smart city with 5G".

For this matter, I am focusing on public sector and more especially on housing, healthcare and transportation.

Therefore, my goal is to know how 5G could enhance those sectors in Luxembourg, and be useful for them to overcome the challenges the city/country is facing. In my questions you will find 3 main divisions:

- 5G
- Luxembourg
- Smart city

Please, be as specific as you can, and give as many details as you wish.

5G-specific questions:

1. According to you, what are the main advantages of 5G?
2. According to you, what are the main disadvantages/challenges/risks of 5G?
3. In your opinion, what are the main differences between 4G and 5G?

Luxembourg-specific questions:

4. What infrastructures should be set for 5G implementation? – Is Luxembourg ready for the implementation of 5G?
5. According to you, what will be the benefits of implementing 5G in Luxembourg? – what is going to be new in comparison with the use of 4G?
6. What do you think will be the main challenges Luxembourg will face while implementing 5G? – and more especially in terms of healthcare, transportation and housing

Smart city-specific questions:

7. How do you think 5G could enable Luxembourg to become a smart city or even a smart nation?
8. How do you think 5G would impact/challenge and benefit in Lux:
   a. Healthcare
   b. Housing
   c. Transportation
9. What do you think would be the greatest area of improvement (in the Public Sector)? Why?
10. Is there anything else you would like to add?

Many thanks for your help!

Appendix 4. Interview guide healthcare

First of all, I would like to thank you for your time and for your help.

In order to set the background, I am a Master student in Management of IT. I have to write a thesis for which I chose the following topic: "Luxembourg's evolution from city to smart city with 5G".

For this matter, I am focusing on the public sector and more especially on housing, healthcare, and transportation sectors.

Therefore, my goal is to know how 5G could enhance those sectors in Luxembourg and be useful for them to overcome the challenges the city/country is facing.

In the present interview, we will only talk about the healthcare sector, as your expertise on the latter can add crucial insights to my research.

Please, be as specific as you can, and give as many details as you wish.

1. According to you, what are the main challenges the hospitals are facing in Luxembourg?
2. Do you have an idea of a way those difficulties could be minimized?
3. 5G is the fifth generation of internet mobile connectivity. It allows higher speed for downloads as well as much faster sending of data, a larger coverage and more stable connectivity.
4. According to you, what could be useful to set up in hospitals in the future?
5. What do you think 5G could enable and enhance within the hospital?
6. Do you have anything else to say related to health?

Many thanks for your help!

Appendix 4. Interviews analysis method

In-depth individual interviews have been achieved in order to not bias one's opinion about the topic and to have a deeper understanding of it. As representing key informants for this research, six experts have been interviewed about their perception on what could 5G bring to Luxembourg in order to make it a smart city.

In order to have realist data, the interviewees are experts of different topics.

This represents then a purposeful sample (opportunistic/emergent). All the experts have been contacted by email, which was the most relevant way to enter in contact with them.

Consequently, semi-structured interviews have been conducted, which allowed the interviewed experts to give entirely their point of view and allowed us to create a real discussion around the topic. The use of semi-structured interviews seemed to be the most relevant in order to gather more helpful and useful information. All interviews lasted about forty-five minutes to an hour and have been recorded after consent of the interviewee in order to make easier the transcription.

Some general questions have been asked first, in order to make the interviewee feel at ease, then leading to some others more precise in order to have real in-depth interviews. The herein used method is content analysis. Indeed, it is one of the most common methods to analyze qualitative data and it is regularly used to examine responses from interviewees. It is used to analyze documented information in the form of texts.

For this matter, we could code the data gathered during the interviews, then assign a topic to each section of the distinct interviews and finally show how it strengthens the hypothesis that 5G can enhance smart cities.

Coding, categories and theme assigned for each parts of the interviews

Firstly, As some information was being repeated between the different interviews, a coding of the information gathered during the interviews has been constructed. Therefore, some code-categories were easier to complete. These main categories are: 5G, smart cities, challenges and current situation for Luxembourg in terms of both 5G implementation and smart city implementation. The document of the coding carried out are available upon request.

Consequently, thanks to the coding and the interviews guides, we could assign a theme to each main category (e.g. current situation in Luxembourg, the country's objectives and the main challenges for its public sector), which has itself been divided into distinct topics such as, for the as-is situation for each sector and challenges and opportunities for each of them for example.

Appendix 5. Survey

Smart Luxembourg

If you are a resident of Luxembourg, this survey is made for you!

This survey is for you to give your opinion about your life in Luxembourg, your needs, as well as your expectations. This would help me identify the general mindset in the country regarding what technological innovations could provide for the country via 5G.

Your response to this survey is anonymous and will be highly appreciated as it will help me develop my Master Thesis, which topic is "How could 5G enable Luxembourg to become a smart city/country". Your collaboration will contribute to helping me pass my Master's degree in Management of IT.

A focus will be made on housing, transportation, and mobility in Luxembourg; so feel free to share your thoughts about your everyday life in the Grand-Duchy!

Answering this survey won't take you more than 5 to 10 minutes.

Thank you so much in advance!

Suivant

Smart Luxembourg

*Obligatoire

Transportation in Luxembourg

This section is for you to give your opinion on your mobility experience in Luxembourg.

How would you rate your overall mobility experience in Luxembourg? *

	0	1	2	3	4	5	
Very poor	○	○	○	○	○	○	Excellent

What kind of transportation do you mainly use on a routine basis? *

- ☐ Car
- ☐ Public transportation (train, bus tramway)
- ☐ Personal bike
- ☐ City bike
- ☐ Autre : _____

How would you rate each of those criteria? *

	Excellent	Above average	Average	Below average	Very poor
Availability of information (traffic, accidents...)	○	○	○	○	○
Traffic	○	○	○	○	○
Quality of roads	○	○	○	○	○
Public transportation (bus, train, tramway)	○	○	○	○	○
Parking possibilities	○	○	○	○	○

How would you describe the overall mobility situation in Luxembourg? *

Votre réponse

What would you improve/set up/change about transportation in Luxembourg? *

Votre réponse

Retour   Suivant

Healthcare in Luxembourg

In this section you can express your feelings about your healthcare experience in Luxembourg

How would you rate your overall healthcare experience in Luxembourg? *

	0	1	2	3	4	5	
Very poor	○	○	○	○	○	○	Excellent

How often do you need the use of healthcare? *

○ Few times a week

○ Few times a month

○ Once a month

○ Once every few months

○ Once a year

○ Less than once a year

How would you describe the healthcare system in Luxembourg? *

Votre réponse

What would you improve/set up/change in healthcare in Luxembourg? *

Votre réponse

Retour   Suivant

Housing in Luxembourg

Here is the section in which you can express your feelings about the housing situation and your housing experience in Luxembourg

How would you rate your overall housing experience in Luxembourg? *

	0	1	2	3	4	5	
Very poor	○	○	○	○	○	○	Excellent

How would you describe the housing situation in Luxembourg? *

Votre réponse

What would you improve/set up/change in housing? *

Votre réponse

Retour   Suivant

5G

"5G is the fifth generation of wireless technology, advances mobile technology in speed, number of permissible connections, latency, capacity, and reliability. It can improve communication between people, but also enable people to interact with the growing ecosystem of connected machines around them.
5G can deliver private, secure and reliable communications, massive M2M (Machine-to-Machine) and IoT communications, real-time data transmission, and enhanced tracking of assets."

Source: KPMG, Unlocking the benefits of 5G for enterprise customers

How soon do you think 5G should be used in Luxembourg in those three sectors? *

	As soon as it is available	Within a year after it is available	Within 2 to 5 years after it is available	In more than 5 years after it is available
For mobility	○	○	○	○
For healthcare	○	○	○	○
For housing	○	○	○	○

Do you think 5G would benefit the public sector? *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Would you fear: *

	Extremely	Moderately	Not at all
Health issues	○	○	○
Reliability	○	○	○
Data protection	○	○	○
Environmental issues	○	○	○

Would you have other fears regarding 5G? *

Votre réponse

What could you expect from 5G in mobility? (if "other", please specify) *

☐ Automated transportation (driverless cars, automated tramways, buses and trains...)

☐ Live information (parking possibilities, traffic jams, accidents...)

☐ Improved car-sharing

☐ Autre :

What could you expect from 5G in healthcare? (if "other", please specify) *

☐ Data transmission between doctors, hospitals...

☐ More reliable telemedicine

☐ Better management of patients in hospitals

☐ Better connectivity in hospitals

☐ More usage of wearable devices (e.g. to track your heartbeat, or to find the closest nurse in hospitals...)

☐ Autre :

What could you expect from 5G in housing? (if "other", please specify) *

☐ Remote visits (by making more effective augmented reality)

☐ Better response to the growing demand

☐ Better pricing

☐ Smart homes/buildings

☐ Autre :

Retour   Suivant

You are

Your gender *

○ A man

○ A woman

○ Rather not say

Your age *

Sélectionner ▼

Your ZIP code *

Votre réponse

Retour   Envoyer

Smart Luxembourg

Your answer has been saved, thank you for your help!

Envoyer une autre réponse

Appendix 6. Survey analysis method

The survey has been sent by many different ways to a lot of different people as explained in Chapter 3. We could gather a total of 109 responses, and will, in this chapter, analyze those replies while completing the gaps of the literature. This will allow us to reply to the sub-question that is "What are Luxembourg's inhabitants' expectations for the future of the city/country?"

The methods used for the survey analysis are the screening method for closed-ended questions and coding for open-ended questions.

The screening approach consists of analysis the results thanks to the numbers (percentages as well as number of people that answered). This, later on, allowed us to draw conclusions.

While the coding consists of building categories of information gathered in order to turn text responses into actionable data. The coding method used herein is the same that have been use for the interviews analysis.
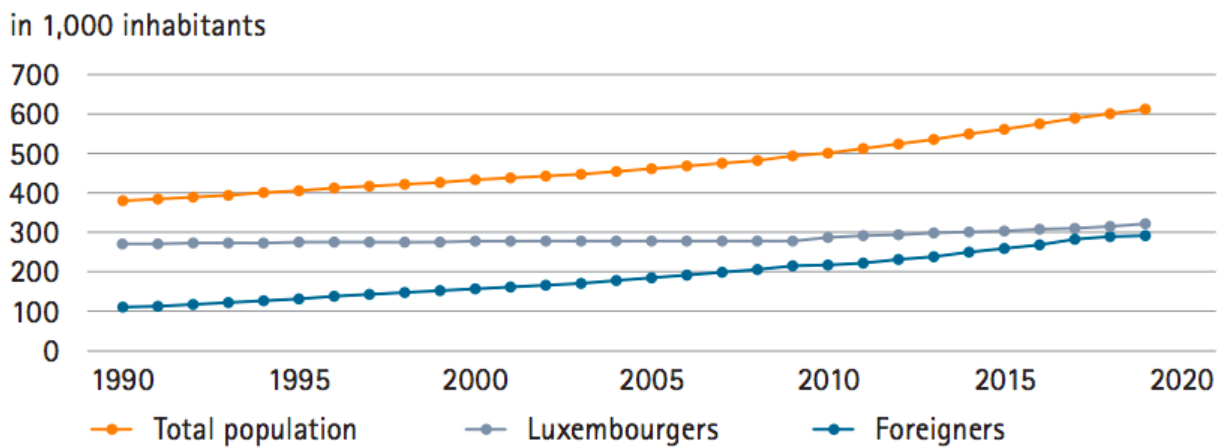
Appendix 7. European Commission's framework for smart cities

European Commission. (2020, April 28). Intelligent Cities Challenge presentation [Webinar]. In ICC Webinar Series. Retrieved from https://technopolis-group.webex.com/technopolis-group/j.php?MTID=m03b0db83e1ca1a2174b4920ea14b5921

Appendix 8. Growth of the population of Luxembourg

STATEC. (2019). *Luxembourg in figures*. Retrieved from https://statistiques.public.lu/catalogue-publications/luxembourg-en-chiffres/2019/luxembourg-figures.pdf