How IOT solutions can help policymakers monitor heat and air quality in urban areas as a part of their smart city strategy?

A case study at KPN telecom and the city of Rotterdam.

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The Netherlands

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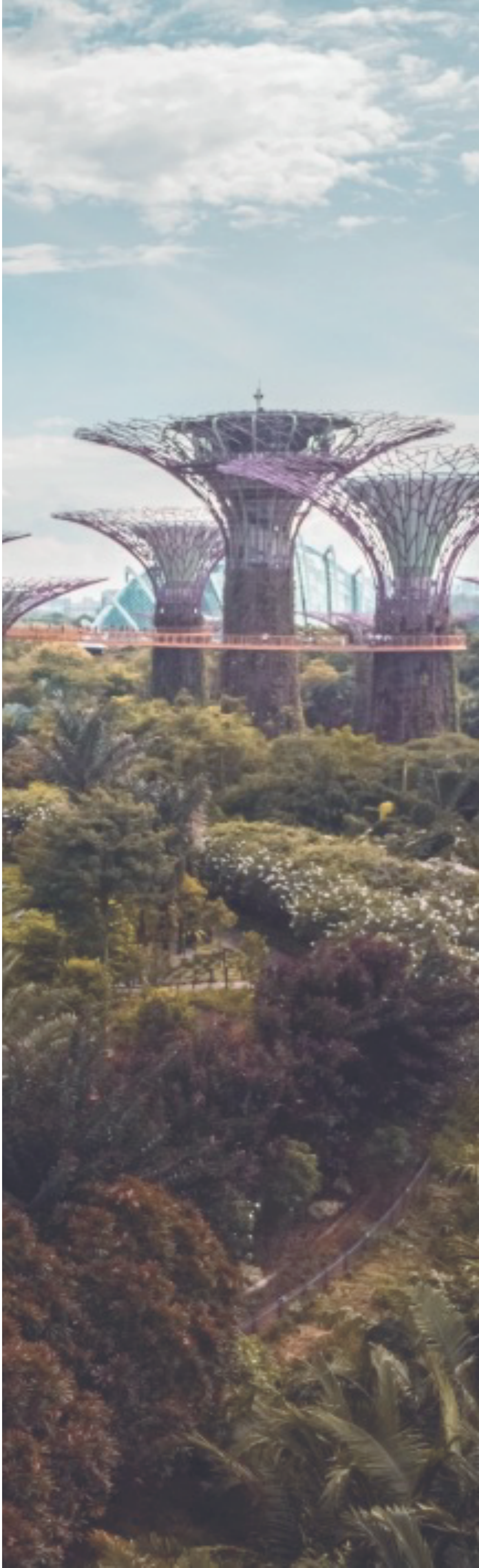

Graduation report
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Acknowledgement

Dear reader,

This research is the outcome of my graduation project of the Industrial Ecology masters at Leiden university and Delft University of Technology. Five years ago, I started my studies at University College London following a bachelor's in urban planning. Since then, my fascination with cities has been rapidly growing. Studying at UCL taught me, that cities can be described as living organism where the interplay of economy and society and other factors create a uniform system. Nonetheless, back then I was missing the dimension of environmental sustainability, which I explored further during my exchange at University of Melbourne. I realised, that cities cannot properly function when sustainability is not accounted for. The past two years I was exploring various dimensions of sustainability studying Industrial Ecology. Through exploration of different concepts related with sustainability I came across data driven smart cities which presumably are the future of our nowadays cities.

Firstly, I would like to thank KPN for providing me opportunity to explore the topic of smart cities with the company. I would like to thank Jeroen for his unconditional support, patience and time spent with me designing this research. I have learned a lot during our journey and enjoyed this research internship hugely. I would like to thank Jean-Pierre for his support and time. During our meetings I learned a lot about smart cities, and how can we realise the smart city dream. Secondly, I would like to vastly thank my supervisory team, Andy and Achilleas for their patience, time, and learning. Thank you, Andy, for your support when I felt insecure and lost, you always guided me in a good direction. Achilleas, thank you for being there for me, even when I was not confident about the research. You supported me and encouraged to take the next steps.

I would like to thank all the experts that supported me, Feiko, Frank and other representatives from the municipality of Rotterdam. Thanks to their help I could gather necessary information and validate the study at the same time learning a lot about the technology, spending enjoyable time. I would like to thank my family, especially I would like to thank to Anna, Andrzej and Gosia who gave me the unconditional support during my educational path. Most importantly, I would like to thank my grandmother, Teresa who always stood by my side, supporting any of my decisions and assisting me greatly throughout this research. Unfortunately, she was not able to wait until the research was completed.

Please enjoy reading this thesis,

Oliwia Popek

Executive summary

Cities are the centres of communication, commerce, and culture. Although, more than 80% of global GDP is generated in urban districts, the cities consume two-thirds of global resources and produce more than 70% of global CO_2 emissions. Rising population, escalating urban pollution, the effects of climate change urge cities to search for innovative solutions that will help mitigating rising urban problems, safeguarding more liveable future for its citizens. Among most pending issues, air pollution and heat stress have been highlighted by significant amount of the scientific research. In the Netherlands, air pollution shortens societal life expectancy by 13 months. Heat stress, on the other side is responsible for the increase in societal morality by 12% during the heat waves. The effects of climate change are predicted to bring more heatwaves in the future creating a significant risk to the vulnerable groups of the society. Recent technological development that embraces more feasible sensing technology, increasing connectivity and advanced computing platforms, creates a vast opportunity to design solutions that will help to map the hotspots of less obvious data like air pollution or heat stress.

This report proposes a monitoring solution that helps thoroughly gather, analyse, and report the data which can be used by the policymakers while designing solutions for urban areas. The solution was defined basing on a set of reference studies that display example practice for air quality and temperature monitoring. The reference studies represent four different monitoring initiatives. In Chicago program called Array of Things is being implemented; Barcelona's smart initiative is called Sentilo; Copenhagen deploys smart solutions through Copenhagen Connecting; Singapore has its Smart Nation Sensor Platform. The reference studies served as an input for identifying a framework that consist of 8 enablers for smart initiative deployment. Further, technology and data analysis and display enablers were explored in detail. The solution composes of four stages namely: Physical infrastructure, cloud, data analysis platform, visualisation, and information hubs. The physical infrastructure includes selection of sensing technology that closely monitors air quality and heat through fixed, mobile, and participatory sensors. The cloud stores and computes data received and sends it to data analysis platform where four engines further analyse and report data to information hubs. City managers and third party can access the information through an application that displays real-time information about air quality and heat, being able to send alerts or predict the most optimal route throughout the city. Further, the information gathered can be envisioned in real time in a 3D model of a city – a Digital Twin. There are other factors that are deemed to be important like partnerships and funding and they are stated in the model, but they were not the focal points of the research and are included in the recommendation section.

Content

Chapter 1: Introduction

For the past decades' rapid development of human settlements, rising population, and higher density in the cities toughly disclosed mounting problems of XXI century urban society. The migration trends and human development caused the formation of highly polluted urban areas that are prone to heat stress. Considering intensifying urban dilemmas and raising awareness of the health and sustainability implication on urban settlers, environmental monitoring and management is becoming a significant issue for the municipalities. To better understand and appropriately manage urban environments it is crucial to monitor closely urban parameters. The data can serve as an input for decision-making purposes while designing policies at different scales. Recent developments of low-cost sensors, available computing infrastructures, and development and deployment of wireless communication networks enable connecting various devices to the internet enabling machine-to-machine (M2M) communication. This creates an immense opportunity to integrate the physical spectrum of the cities with digital technologies assisting new applications to advance environmental sustainability (Bibri 2018a). The advancements include smaller and affordable sensing technology capable of being connected with different devices, the wireless networks (e.g., LoRa, NB-IoT, and LTE-M) delivered by telecommunication operators, that offer a robust connectivity, creation of advanced computing platforms and data hubs and others. Although technology has already been developed and is ready to be deployed, an observable gap exists between the technology that is ready to be deployed and the existing socio-economic system that is unprepared to implement city-wide smart solutions. In the Netherlands the policies for limiting air quality and urban heat are diverse. While for air quality the standards are regulated by international bodies (European Commission etc.) or informed by international standards (WHO) the mitigating of urban heat stress is done per municipality what effects in non-comprehensible solutions. Moreover, the policies are informed by data that has limited resolution, and not comprehensive formats. This research paper argues that novel sensing technology paired with other Internet of Things (IoT) devices can not only increase the data readability but also present advanced solutions for mitigating urban problems that will limit the need for human-to-machine (H2M) interaction and increase M2M communication. This might seem like an impeccable opportunity, but certain barriers exist to the implementation of those solutions.

Research Question and Sub-questions

This section presents the underlying research question and sub-questions that guided the research. The paper seeks to answer the following main research question:

<u>How can IoT solutions help policymakers monitor heat and air quality in urban areas as a part of their smart city strategy?</u>

Sub questions:

1. *<u>What are the main concerns for policymakers when governing air quality and heat stress risks?</u>*
    - *Why it is important to monitor urban temperatures and air pollution levels?*
    - *What are the policies that define limits to air pollution and heat stress in the Netherlands and how are they informed?*

2. *How can IoT solutions for monitoring help bridge the identified data gaps towards desired future state and what are the examples of implementation?*
    - *Which cities are relevant to compare with the case city Rotterdam and why?*
    - *What are the key generic barriers and opportunities strengths and weaknesses for implementing the IoT technology in case studies?*
    - *What are the barriers and opportunities strengths and weaknesses of smart initiatives in Rotterdam?*
    - *What lessons can be learned from these international reference cities and how the lesson learned can be implemented in Rotterdam?*
3. What is the proposed solution for IoT monitoring of air quality and temperature?
    - What are the focus points of the strategy?
    - What are the further recommendations?

Methodology and Structure

This section explains the methodology that guided the conduct of research underpinning this master thesis. The thesis aims to deliver a recommendation and framework for deployment of the IoT air quality and heat monitoring solutions in a Dutch case study – Rotterdam basing on a global benchmark, examining the initiatives in four case studies. The following section explains the structure of the research.

The objectives of this research are as follows:

- Present the findings delivered from the literature research and interviews with experts and practitioners who advance the technology behind Smart Sustainable City, with a focus on, but not limited to the Netherlands.

- Identify and describe a set of case studies where the digital infrastructure is implemented to improve urban liveability with the relation to urban heat and air quality.

- Build an inventory of key enablers for smart monitoring strategy.

- Propose and justify a recommendation for monitoring technology and data analysis applications for Rotterdam and justify a framework that will inform Rotterdam municipality on different issues that should be addressed in short- to medium- term to advance air quality and urban heat objectives through a smart city strategy.

To fulfil these objectives, a methodology was defined, including 1) literature research through a qualitative analysis based on narrative reviews of scientific publications and policy documents; 2) assessing the state of practice based on qualitative case study analysis of initiatives and interviews with experts; 3) synthesizing the findings of the research and the case studies into a conceptual framework, and 4) providing recommendations.

Chapter 1,2 & 3:

*Research Literature Revie*w to identify the current urban trends and their outlook identifying the research gap and justifying the study. This section includes:

a. *problem statement which defines the issues linked with the topic of this research and explains the alignment with Sustainable Development Goals.*
b. *the background research that informs about current urban issues related with climate change, growing population, link between heat, air quality and vulnerable societal groups outlining the sustainability goals for improvement.*
c. *Current strategies for monitoring air quality and heat in the Netherlands*
d. *Digital environment section that debates about IoT enabling technology*

Chapter 4:

Case Study Development to document four case studies that embody IoT strategies that focus on air quality and heat stress and including literature research but also experiences of practitioners and experts that help develop sustainable cities. This section includes:

e. Selection of four case studies basing on number of factors
f. Summary of strengths, weaknesses, opportunities, threats.
g. Rotterdam analysis
h. Key enablers of the smart monitoring strategy.

Chapter 5:

Conceptual Framework to propose a framework to guide the process of solution implementation based on the inputs obtained from research literature review, policy literature review, case study development activities, and expert's output. The framework delivers a set of enablers, from which two enablers are further evaluated.

Chapter 6:

Validation of the Findings to organize a meeting with government practitioners, IoT field experts to discuss and provide feedback and validation to the findings.

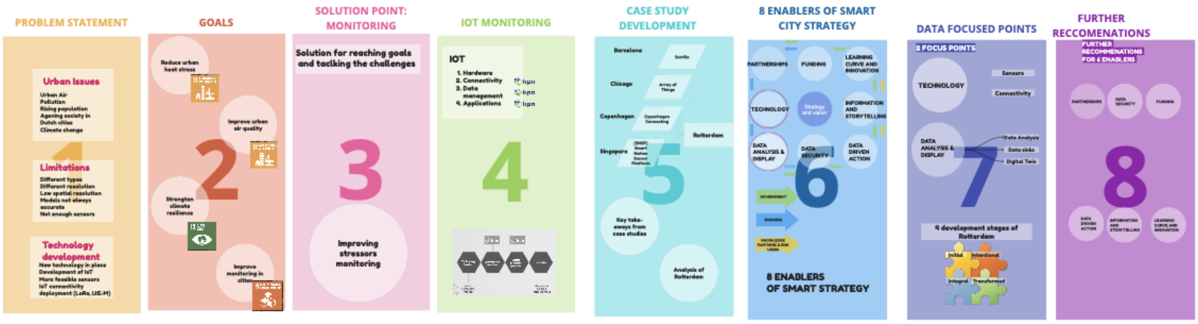


Fig 1. Research flow characterised in eight steps.

The research flow includes eight steps. Firstly, the problem statement that includes three main points was defined, what follows the outlined problems were linked with the existing sustainability framework and three SDG's. Thirdly, the solution point was described urging for better monitoring of the phenomena. Section four focuses on the digital environment and potential benefits that are linked with wider deployment of IoT technologies for monitoring. The fifth step defines international case studies measuring key take-aways from the international practice. While take-aways serve as an input for defining the key enablers of smart city strategy, later sections focus on two key monitoring enablers – technology (hardware) and data analysis and display platform. Last step was to deliver further recommendations for smart framework for Rotterdam.

Main shortages & research gap

This section characterises the research gaps defined by literature research. It includes three main shortages: Urban issues, Limitation, and Technology development. The research gap was observed especially in a local context of Rotterdam. Table below summarises main issues and gaps observed.

Shortage	***Gap***	***Details***
Urban issues	*Society& Climate*	Numerous pre-mature deaths are caused by air pollution Elderly group is more susceptible for heat Dutch ageing society is growing in the cities. Cities are more at risk of heatwaves than countryside.
Limitations	*Scale*	Air Quality and Temperatures differ highly at the local level and remote sensing is not able to recognize those differences.
	Format	Lack of uniformity between collected data (i.e., different spatial, temporary distribution envisioned by different mapping tools).
	Methods	Currently, information gathered by conventional methods (i.e., remote sensing and sensor data) needs to be supported with models.

	Local context	No smart solutions exist in Rotterdam that monitor air quality, and heat with IoT.
Technology development	*Transformation*	Technology for IoT monitoring of HS and AQ is already in a place, but society is not yet ready for implementation due to the complexity of the systems

Table 1. Summary of limitations & research gap

Research gap

A research gap was observed in both, in the general scientific research and in the local context - Rotterdam. There is a wide collection of research papers that discuss IoT monitoring (WEF 2018), Smart Sustainable Cities (Estevez 2016; Liu 2018; Höjer 2014; Bibri 2018;) and other topics related with smart city technology, nonetheless, most of the research focuses on other than heat and air quality monitoring themes. Some (Ahlers 2018; Miles 2018; Kumar 2015) discuss the potential improvements in monitoring of air quality with IoT, but the research is still in its theoretical stage having no real examples of case studies where the solutions are fully deployed and working. In some cases, research was conducted on IoT monitoring for air quality but most of the literature focuses on specific segments of solutions i.e., sensors or platform only (Gubbi 2013; Beckman 2017) not designing a comprehensive solution. Additionally, most of the research looks either at air quality or heat variable alone not considering both at the same time.

Locally speaking, Rotterdam has a limited amount of research that focuses on city transformation towards smart city. The problem of urban heat stress in Rotterdam has been defined by research papers that mostly base its spatial analysis on models and remote sensing which is not as accurate compared with land sensors (Nijhuis 2011; Klok 2012; Hoeven 2015;). Additionally, no research was conducted on delivering IoT solutions for heat monitoring and air pollution in the city and therefore this gap must be filled.

Urban Issues

Air pollution is one of the most critical urban issues that impacts each inhabitant causing 4,6 million pre-mature deaths per year (WHO, 2021). Urban heat stress, triggered by unmethodical city development, causes a threat for older and vulnerable societal groups. Urban heat stress is projected to be more impactful due to the climate change effects. Thus, the Dutch government mentions urban heat stress as a leading apprehension to tackle, bearing in mind ageing Dutch urban society that is predicted to double by 2040.

Limitations

While air quality has been significantly improved over the past decades, especially in western societies, urban heat stress has been more impactful over the last two decades. When air quality standards are well defined by international and national directives, urban heat seems to be omitted by the regulations and standards. Globally, a significant number of peer-reviewed articles have been published discussing heat stress for a diverse number of case studies. For major cities (e.g., Amsterdam and Rotterdam) the spatial analysis of urban heat has been designed informed by remote sensing data and remote units. In the Netherlands data that informs the municipalities about the state of urban heat is partially retrieved using hobby meteorologists' data (Hove et al. 2011), by means of mobile units (e.g. cargo bicycles)(Municipality of Amsterdam 2020; Nijhuis 2011), using satellite imagery to map land surface temperature variations during hot days (Hoeven and Wandl 2015). Although, the resolution of data is improving over time, the temperature differences in Urban Canopy Layer (UCL) vary on a street cross-section and therefore needs to be better monitored. Satellite data is influenced by atmospheric contortion which hampers data readability. Lastly, the data should be available on a timelier basis (i.e., temperature data retrieved every hour) so the municipalities can react more accurately to changing conditions.

Some researchers indicated lack of transparency and uniformity in the current techniques for a multiscale urban heat phenomena mapping. The integration of multiscale and multidisciplinary tools for mapping and data interpretation seems to be lacking (Icaza 2017). Some observe a significant gap between technologies enabling the urban heat monitoring (e.g. remote sensing, ground sensing) and the local policies that focus on UHI in medium-size cities (Icaza 2017).

Technology development

Researchers have been disputing about digitally-enabled air quality and heat stress monitoring techniques for almost a decade now (Kumar et al. 2015; Majumdar et al. 2021; Traboulsi and Knauth 2020; Xiaojun, Xianpeng, and Peng 2015). Recent progress in development of low-cost micro-scale sensing technology is fundamentally altering the conventional monitoring approaches enabling real-time information in a compact form (Kumar et al. 2015). The development of low-cost sensors connected to wider IoT network gives an immense opportunity to increase the monitorability of urban air pollution and temperatures. On top of that growing importance of IoT applications is observed cross many sectors (healthcare, agriculture, transportation, manufacturing etc.,). To enable IoT development number of factors had to be in place to ensure exponential rise of IoT. Caragliu et al., (2015) defines four IoT enablers: **Price erosion** (decreasing price of sensors that allows wide-use of the sensing technology, **Ubiquitous wireless coverage** (different types of networks - WiFi, 3G/4G and LoRa are in place to ensure connectivity of the sensors), **Abundant processing and storage capabilities** (Larger capabilities of processing the data and automated analysis) and **IPV6** (New Internet Protocol allowing unlimited number of IP's) (Caragliu et al. 2015). Together, enablers create an immeasurable opportunity for improving urban living.

Motivation and Industrial Ecology relevance

The main contributions of this work include the findings from the literature research, containing identification of problems with the regard to urban areas; a case study analysis of Smart City initiatives conducted by city governments often partnering private sector from around the world to address the AQ and UHI issues; identification of key enablers and barriers for successful implementation of the digital environment; a conceptual framework designed for a Dutch case study; define barriers and opportunities of such implementation and recommendations to advance smart city innovations.

This research is focused on major sustainability urban issues that relate to the urban environment and the wellbeing of the urban population. Emphasising sustainability problems, the research suggests possible solutions displaying technical, environmental, and societal perspective on sustainability. Serving as an advice for the policymakers, the research strongly accounts for different interest groups considering different perspectives on the problem. Accounting for system perspective, the research takes an interdisciplinary approach blending various concepts that relate to urban systems and digital improvements basing on synthesis of methods and concepts. The main goal of the research is to improve the condition of the urban areas, increasing the monitoring capabilities that will lead to better informed decision-making and more sound policy design.

Chapter 2: Background Information

This chapter presents the background information by means of a literature review and outlines the academic research gaps in monitoring air quality and heat stress in cities. The background research is based on the extensive literature review. This chapter is divided into three sections: urban challenges, technology limitations and technology development to furthermore delineate the problem statement. Particular attention is moreover devoted to the concepts of urban heat island effect, and the implications of air pollutions in urban spaces, current urban population trends and the effect of climate change. This chapter puts an emphasis on sustainability concept and the need for improving services in urban areas outlining the data shortage in the current field of monitoring. The goal of the chapter is to present the challenges linked with urban heat stress and air pollution, answering the research question and sub questions:

What are the main concerns for policy makers when governing air quality and heat stress risks?

- *Why it is important to monitor heat stress and air quality?*
- *What are the policies that define limits to heat stress and air quality in the Netherlands and how are they informed?*

The main findings of this chapter are as follow: rise of urban population will be significant over the next three decades. Moreover, climate change already has a significant impact on cities and will cause more impactful consequences in the future. A strong correlation between age and heat stress exists causing serious threat to elderly communities. The table below summarises the background information.

Topic	***Details***

Rising urban population	By 2050 it is expected that almost 70% of world's population (6,7 billion) will be living in the urban areas, The number of people living in cities over the age of 75 will double to 2,5 million by 2040
Climate change	Over the next 30 years more than 970 cities will be regularly exposed to the hottest 3-month average maximum temperatures reaching at least 35°C. In the Netherlands one of the most urgent climate change effect to tackle is urban heat stress
Urban Heat Stress	50% of urban districts in the Netherlands experience heat stress at least 7 days a year During the heatwaves in the Netherlands morality is rising by 12% (about 40 extra deaths per day).
Air Quality	In the Netherlands, air pollution decreases societal life expectancy by 13 months which is more than disability-adjusted life year (DALY) Amounting at 5000 additional deaths yearly in the Netherlands.
Sustainability	This research addresses air quality, rising temperatures in the cities and the technology that will help better monitor those aspects. And therefore, it directly touches on three SDG's: 9 (industry innovation) 11 (sustainable cities) and 13 (climate action).

Table 2: Summary of background information

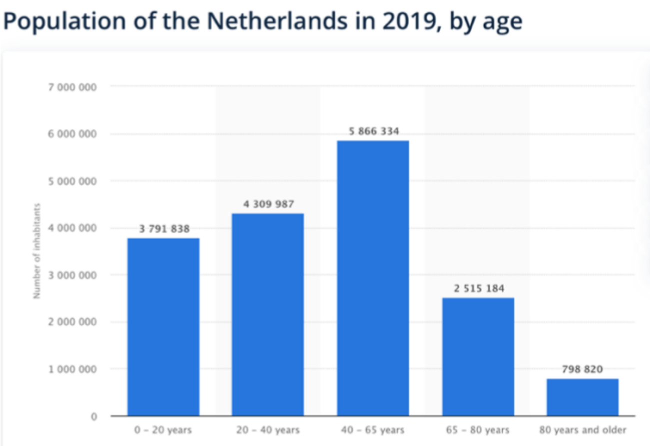
Rising urban population

Global growth of urban population paired with the increased urban resource intake has put significant pressures on cities. Major shifts in socio-economic activities have moved the agricultural model of the society to a manufacturing and service-based one. In 2018 55.3 % of world's population lived in urban regions (4.2 billion)(UN, 2018). By 2050 it is expected that almost 70% of world's population (6,7 billion) will be living in the urban areas (UNDESA, 2018). In 2018, highest percentage of people living in urban areas was marked in North America (82%) followed by Latin America and Caribbean (81%), Europe (74%) and Oceania (68%). Approximately half of Asia's population lives in the cities whereas Africa's urban population only accounts for 43%. Those numbers are predicted to drastically change in the future. According to UNDESEA report, less developed regions are already taking a lead in rising urban population and are expected to take approximately 82% of world urban population in 2050 (UNDESA, 2018). Changing urban population patterns will cause a significant rise in numerous cities, especially in developing countries (UNDESA, 2018).

The Netherlands is the most densely populated country in Europe (excluding small city-state countries e.g., Monaco) and is the 16th most densely populated country in the world having 424 people per square kilometre. Over a decade (2009-2019) the percentage of people living in the Dutch cities grew from

86,3% to 91,90 % (Statista 2021). The characteristic factor about the Netherlands is its dense network of medium-sized cities interconnected with a dense public transportation system. There is no city in the Netherlands that exceeds a million inhabitants. There are 23 medium-size cities with a population between 100,000 and 1 million people including 5 of the biggest cities: Amsterdam, Rotterdam, The Hague, Utrecht, and Eindhoven. There are 265 smaller cities with between 10,000 and 100,000 people (World Population Review, 2021).

On average, the Dutch population is 42,7 years old being one of the oldest populations in the world (see Fig. 2). In 2019, two-thirds of the population were older than 40 years (Statista, 2021). Netherland's Environmental Assessment Agency (PBL) outlines that the number of people over 75 will double to 2,5 million by 2040. The numbers are set to increase especially in urban areas (Fig 3). High rates of urban density combined with aging society and uncertainty of climate change effect on different cities create a strong motivation for investigating the ways for reducing the impact of heat stress in the cities. If not tackled efficiently, the heat stress will lead to an increase in death rates in urban areas (Hove et al. 2011; PBL 2015).



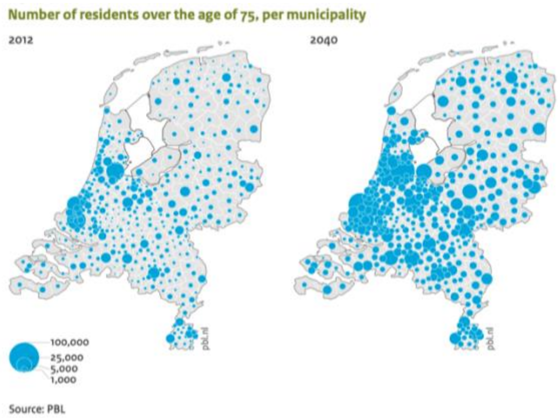


Fig. 2&3. Population of the Netherlands in 2019 by age (source: Statista, 2021)
and number of residents over the age of 75, per municipality (source: PBL, 2015).

Climate change

The effects of climate change have been clearly visible since the mid-20th. NASA (n.d.) outlines that the global temperature has risen on average by 1.8 (degrees Celsius) since the late 19th century. Most of the warming occurred over the past four decades. Past 7 years were the warmest on record. Oceans have warmed about 0,33 degrees since 1970. Although unsignificant, the average 1.8 degrees is causing major disruptions in cities (NASA, 2020). The Global Risks Report 2021 (WEF, 2021) sees climate change action failure second most immediate threat to society among environmental risks (second after infectious diseases). The realization of climate change is unavoidable and denotes that, global cities will be forced to adapt to the coming climate variations (IPCC, 2014). UCCRN has prepared an overview of risks related to climate change. One of the major threats highlighted is <u>extreme heat</u> (Fig. 4) that currently influences 354 cities. The extreme heat section displays the total number of people living in cities where they are regularly exposed to the hottest 3-month average maximum temperatures reaching at least 35°C (95°F).

Vulnerability	Time Period	Total Urban Population at Risk	Recommended Population Estimate	Total Number of Cities
EXTREME HEAT	Present Day	208,990,959	Over 200 million people	354
	2050s	1,669,421,721	Over 1.6 billion people	972
EXTREME HEAT AND POVERTY	Present Day	26,122,791	Over 26 million people	239
	2050s	214,947,227	Nearly 215 million people	495
WATER AVAILABILITY	2050s	656,554,977	Over 650 million people	507
FOOD SECURITY	2050s	2,573,946,040	Over 2.5 billion people	1,649
SEA LEVEL RISE	2050s	835,581,329	Over 800 million people	572
SEA LEVEL RISE AND POWER PLANTS	2050s	472,092,384	Over 450 million people	236

Fig. 4. Overview of climate change related impacts (UCCRN 2018)

While a uniform cross-city reporting on effects of climate change has not been implemented yet, efforts have been made to estimate current impacts of climate hazards on cities. Carbon Disclosure Project (CDP) assessed that in 2018 out of 620 global cities participating in the study 530 reported on climate hazards (i.e., flash/surface flooding, heat waves, rainstorms, extreme hot days, and droughts) (Fig.5). The study demonstrates that most significant issues cities are currently tackling is extreme heat, floods, and droughts.

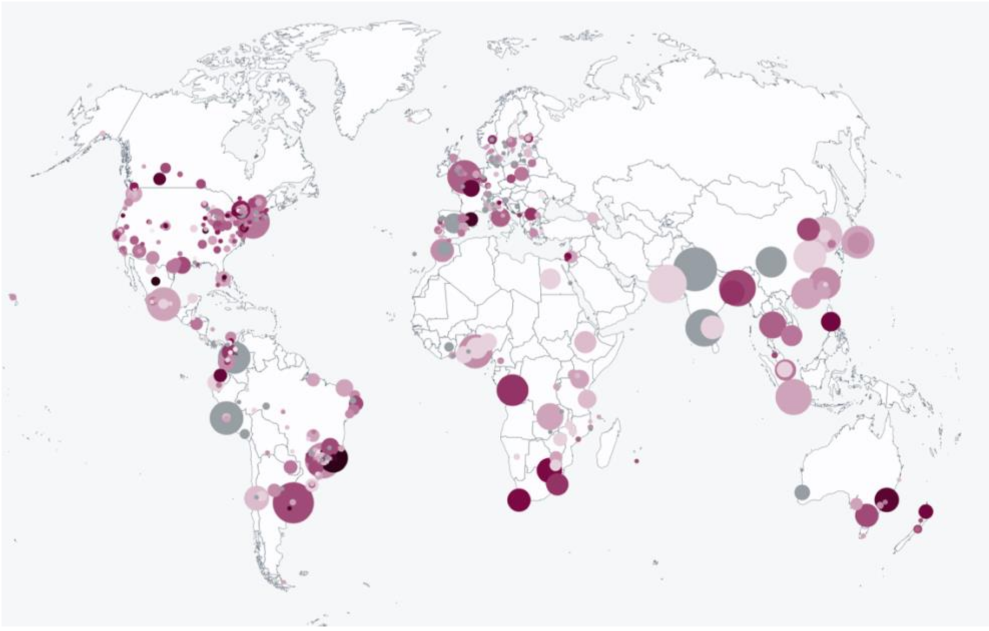


Fig. 5. Climate hazards per city (darker colour mean higher hazardous score) size of the bubble reflects the city population (CDP, 2020).

Most of the hazards occur in a short term (60%) and have medium or high likelihood of occurrence. Long term hazards have been less frequent (11%). Out of long-term hazards 77% is ranked as serious or critically serious threat to cities (see the table 3.).

Hazard:	**Short term: 464***	**Medium:220***	**Long term: 78***
Extreme heat	147	72	17
Floods	176	70	26
Drought	56	40	17

Table 3. Displays number of cities that has experienced serious hazards due to climate change in 2018. (CDP, 2020)
**Total, including serious and less serious hazards.*

Nowadays, at least 354 cities experience urban heat stress with an average summer temperature higher than 35˚C. It coarsely equals to 14 % of the global urban population. Over the next 30 years more than 970 cities will be regularly exposed to the hottest 3-month average maximum temperatures reaching at least 35°C. Consequently, the urban population exposed to the summer heat will rise by 800% in 2050, which translates to 1.6 billion people exposed to urban heat. Events such as the European 2003 heatwave, caused a death toll of 70.000, or 2015 heatwave in South Asia resulted in 3,500 deaths will become more severe in the near future (UCCRN 2018).

Climate change: The Netherlands

While some positive impacts of climate change for the Netherlands are possible (PBL 2015), the negative effects are predicted to have serious consequences for the country. The Dutch Council for the

Environment and Infrastructure highlights that urban heat stress will largely affect people in a near future (PBL, 2015).

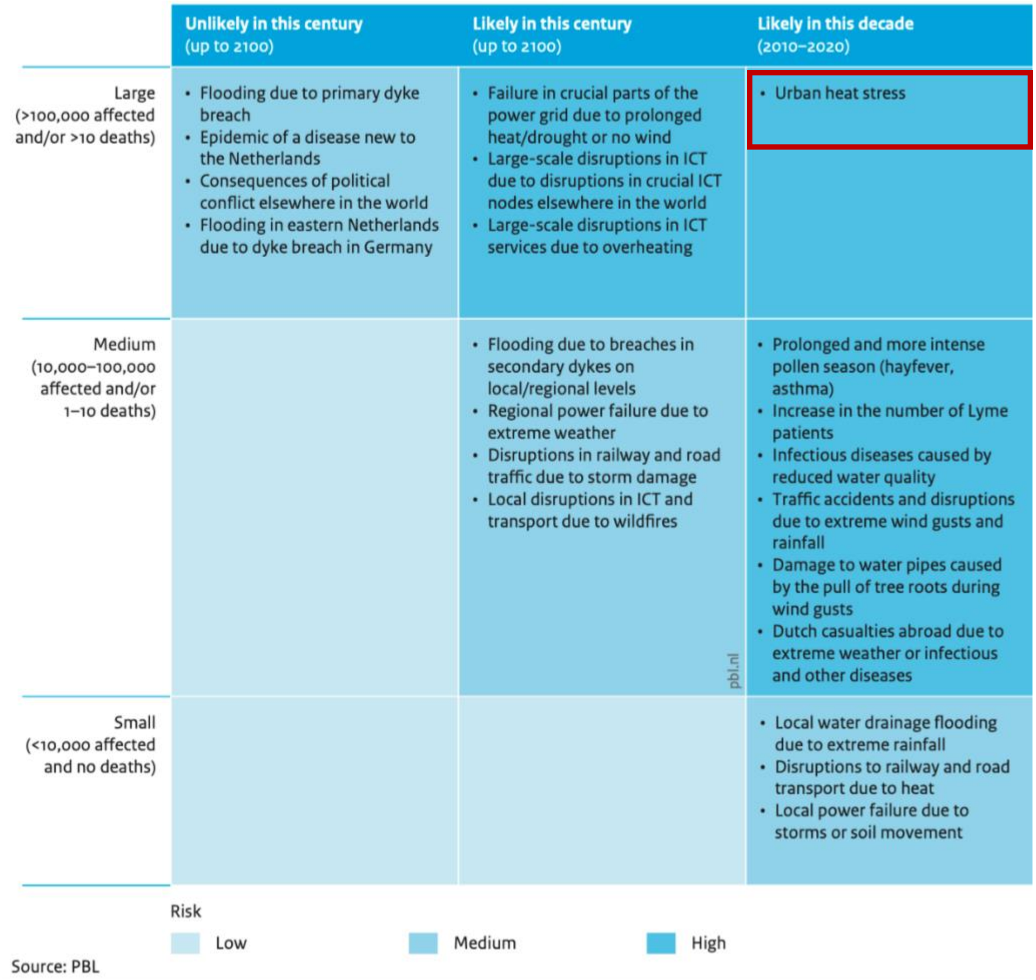


Fig. 6. The effects of climate change on people (PBL 2015)

The Royal Netherlands Meteorological Institute (KNMI) suggests that climate change will alter the weather patterns; winters will become much wetter and less cold and on the contrary, summertime in the Netherlands will become drier and much warmer. The summer heatwaves will be longer and more intense, causing prolonged periods of drought (KNMI. 2014).

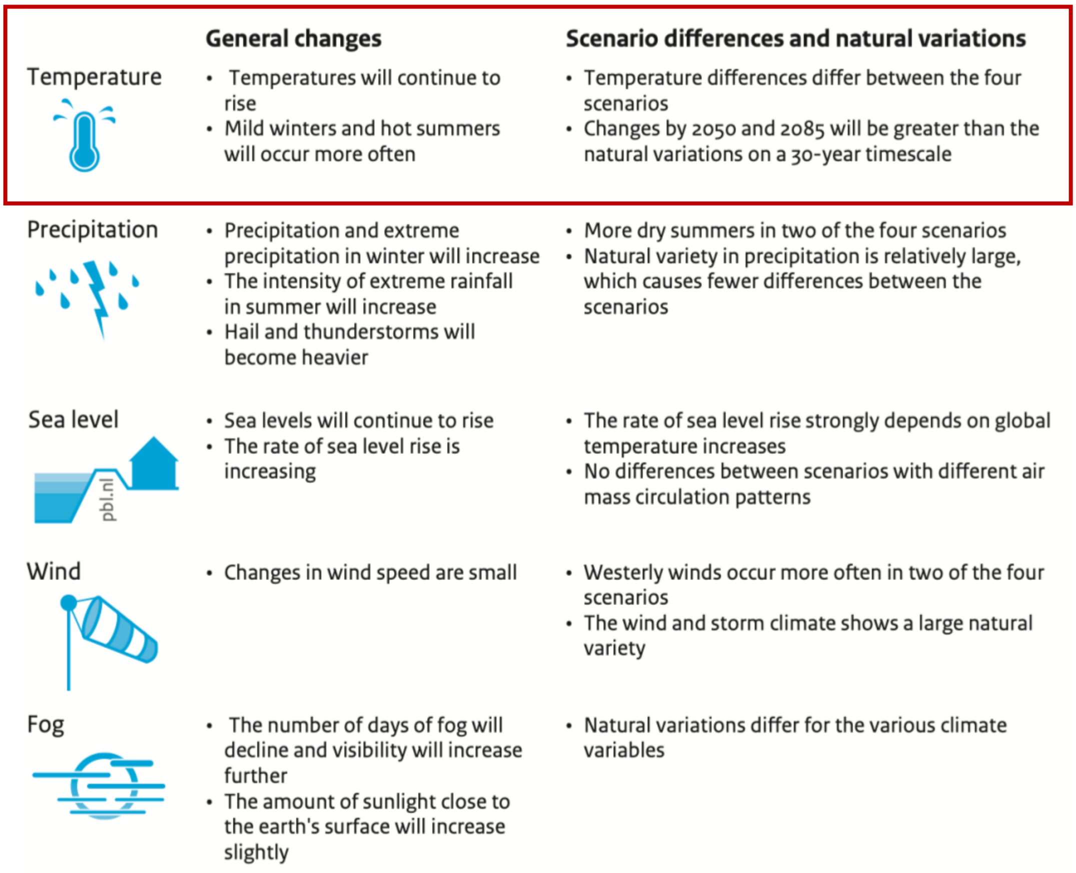


Fig. 7. Changes to the Dutch Climate (PBL 2015)

PBL outlines that currently one of the most urgent climate change effect to tackle is urban heat stress. The increased heat stress will influence more than hundreds of thousands of people in the coming decades. Urban heat is one of the main threats to urban population especially to the older city inhabitants. The repeated events of heatwaves are predicted to trigger an increased number of health problems and deaths among society groups susceptible to indicated weather conditions i.e., elderly or very young (PBL 2015). This mostly concerns larger cities – i.e., Rotterdam, Amsterdam, The Hague, Utrecht. Some researchers confirmed that 50% of urban districts in the Netherlands experience heat stress at least 7 days a year (Steeneveld et al., 2011).

Climate change effects paired with changing societal trends in Dutch urban areas (i.e., predicted inflow of elderly society to the cities over the period of next decades) poses significant challenge for the cities and the adaptation strategies (Hoeven and Wandl 2015; PBL 2015). To mitigate the heat stress in the cities a mix of solutions is required to become better prepared for hotter and longer heatwaves periods including physical infrastructure, mitigation policies that are data-driven, improved monitoring and societal actions (Hoeven and Wandl 2015).

The exposure of urban population to warm temperatures is gradually becoming a public health concern. Cities, concentrating noteworthy portion of population are especially susceptible to temperature stress, not being able to ensure efficient mitigation of high temperatures. Globally, extreme temperatures kill about 5 million people each year (Lu & Cox, 2021). In the Netherlands the heat stress occurs as the effect of heat waves. The heatwaves are stronger in urban districts because of the heat island effect (Fig. 8).

The main impacts of urban heat stress include the increased energy consumption, elevated emissions of air pollutants and GHG, compromised human health and comfort, impaired water quality. Furthermore, many studies indicated a strong correlation between age and susceptibility to higher temperatures. Kenny et al. highlighted that people aged 60 and above are the most at risk due to high temperatures and the most affected by extreme heat (Kenny et al. 2010). Heat affects older but also people with obesity, pulmonary disease, cardiovascular disease, or long-standing diabetes due to inability of the organism to accurately regulate body's temperature. It is recommended to have access to cooler environments during extreme heat (i.e., air conditioners, access to transportation, water features etc.). Society should be more aware of the heat-related risks. Moreover the urban environments should be closely monitored to appropriately respond to extreme heat (Hatvani-Kovacs et al. 2016; Kenny et al. 2010).

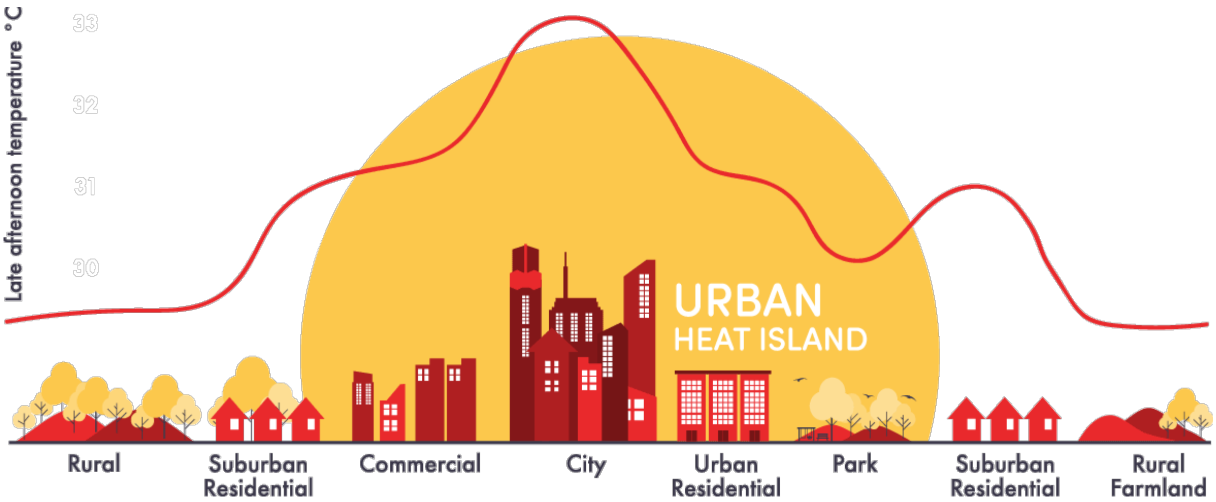


Fig. 8. Visualisation of urban heat island effect (source: coolparramatta.au)

The Urban Heat Island (UHI) occurs due to urban-specific built environment (high degree of hard surfaces, densely built structures). In general, cities tend to have the higher temperatures than surrounding areas. It is due to the changes in radiative and thermal properties of urban infrastructure and the impact of urban structures on local climate (e.g. taller buildings reduce the rate of city cooling at night) (Hove et al. 2011). For Atmospheric urban heat islands there are two types of heat (Fig.9): Urban Canopy Layer (UCL) i.e., in the layer of air where people live, from the ground to below the tops of trees and roofs and Urban Boundary Layer (UBL) that starts from the rooftop and treetop level and extend up to the point where urban landscapes no longer influence the atmosphere (Hove et al. 2011). This research will consider only UCL which is more appropriate boundary for people.

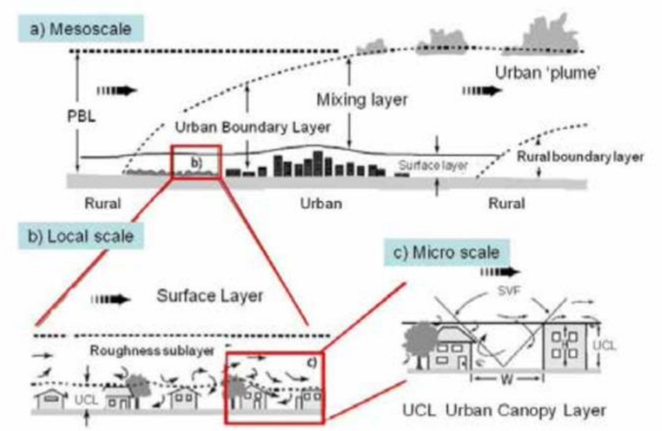


Fig. 9. Schematic representation of climatic scales and vertical layers found in urban areas. Planetary Boundary Layer (PBL), Urban Boundary Layer (UBL) and Urban Canopy Layer (UCL). (Oke, 1987).

The UHI makes cities more prone to heatwaves which might trigger worse air quality and what follows heart stokes, dehydration, cardiovascular complications, and death of the citizens *(ibid*). The most vulnerable to persistent extreme heat conditions are some groups of the society including children, elderly, and the people with health condition. This argument is especially valid for eldering Dutch urban society. During the heatwaves in the Netherlands morality rises by 12% (about 40 extra deaths per day) (TNO, n.d.). It is crucial to understand the impact of heat stress on urban regions identifying hot spots. This can help municipalities focus its interventions where they are most needed during heat waves. Furthermore, when considering the stressors of air pollution and heat stress, studies found connexion between increased temperatures in urban districts and augmented air pollution levels exhibiting a positive correlation with PM2.5 (Eanes et al. 2020).

The effects of urban heat on Rotterdam have been studied in the Hotterdam report that displayed an increased death rate during the summer season of 2006. The report made the explicit link between the death rates and temperature peaks in the city (Fig. 10). In July 2006, more than 1000 people died from heat-related causes in the Netherlands.

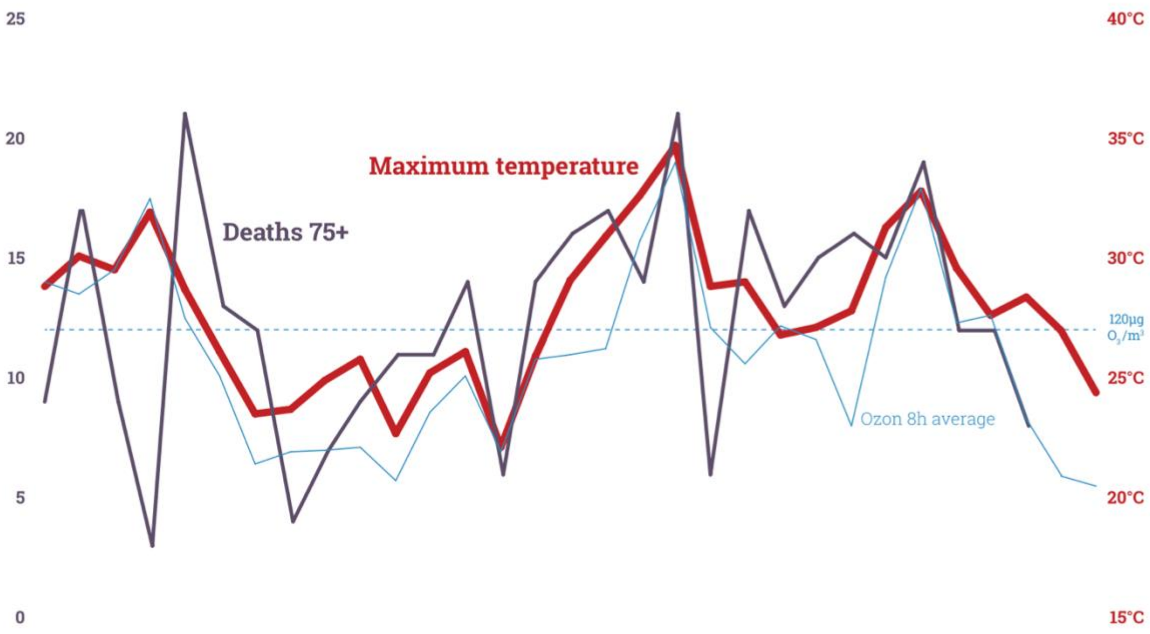


Fig. 10. Relation between heat and death rate. (Source: Hoeven and Wandl 2015)

Air Quality

Any chemical compound that occurs in abnormally high concentrations in the environment can be considered as air pollutant. OEDC has identified two major groups of pollutants that include traditional ones and hazardous pollutants (OECD, 1995). Traditional pollutants (Fig.11) include nitrogen oxides (NOx), Sulphur dioxide (SO2), carbon monoxide (CO), lead (Pb), particulate matter (PM), ozone (O3) and volatile organic compounds (VOCs). The pollutants (e.g., CO, NO_x, VOCs) come from burning of petrol and diesel. Particulates (PM_{10} and $PM_{2.5}$) are the most hazardous traditional air pollutants and occur as the effect of physical processes in the city (e.g., resuspension of dust, vehicle breaking etc.).

Moreover, the traditional pollutants can be distinguished between stationary and mobile air pollutants. When stationary pollutants are associated with fixed pollutant sources (i.e., fossil power plant, refinery etc.), mobile air pollutants include nonstationary pollution source (i.e., vehicles). This research will consider both categories as both are relevant for the urban areas with special attention to motor vehicle which is a leading and the most emerging cause of urban air pollution (Lim et al. 2009).

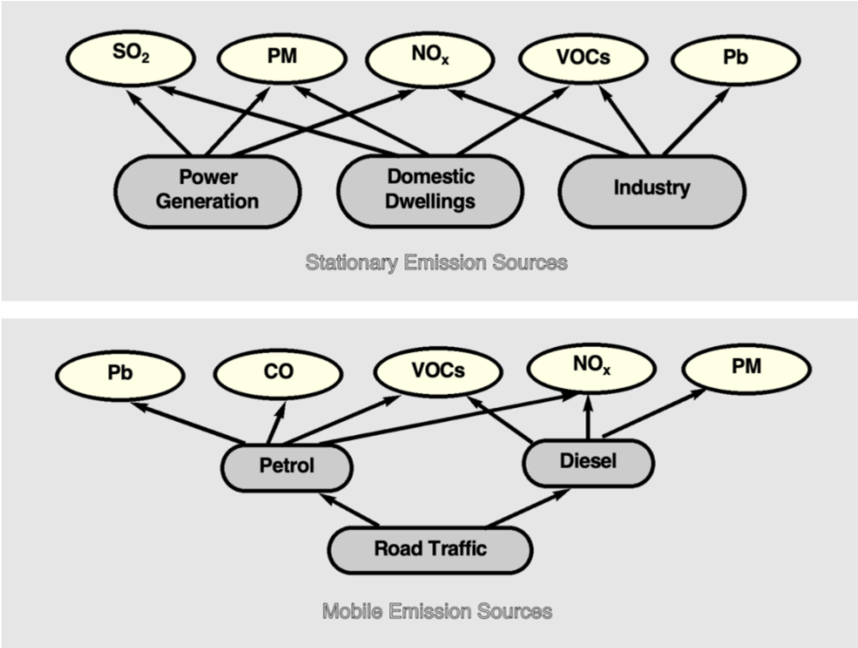


Fig. 11. Sources of various air pollutants

According to WHO, air pollution kills 7 million people yearly. In cities, UNEP estimates one million of premature deaths linked with urban air pollution. Air pollution costs around 2% of GDP in developed countries and 5% in developing countries (Goodsite and Hertel, 2012).

In the Netherlands, air pollution decreases societal life expectancy by 13 months which is more than disability-adjusted life year (DALY). Exposure to particulates is responsible for nine months' loss of life and exposure to nitrogen dioxide (NO2) shortens life expectancy by a further four months (Maas, 2015). Although the air quality has increased since beginning of the century, it is still responsible for almost 5000 additional deaths yearly in the Netherlands (Fig.12).

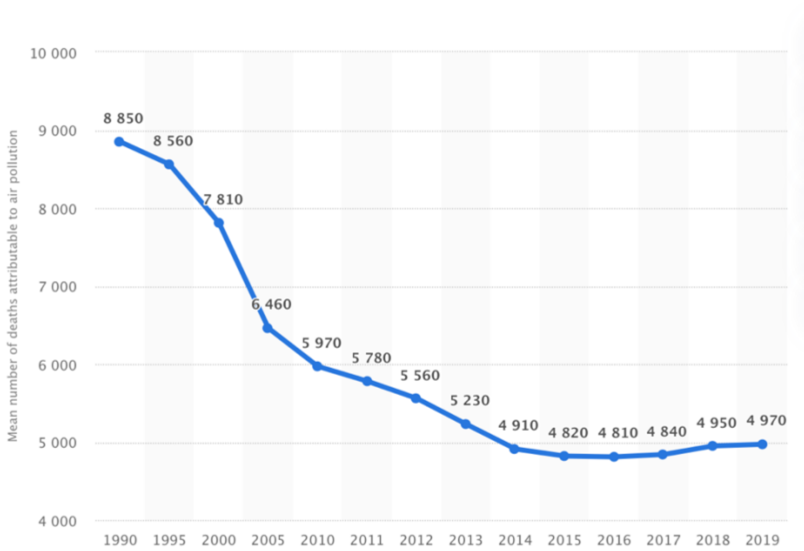


Fig. 12. Number of deaths from air pollution in the Netherlands (1990-2019) (source: Statista 2020a)

Urban air quality is influenced the most by regional transport and industry (e.g., emissions from coal power plants, construction). The pollution patterns differ depending on physical location of a city, size of a city, the methodological conditions (as they direct the dispersion conditions and the pollutant flow), population density and mitigation measures in place.

Local scale differences

Differences in air pollution levels largely fluctuate depending on the street type, environmental surroundings but also on an emitter i.e., vehicle type. Some focus on different scales of the region differentiating pollution concentration in regional city and street increment (Fig. 13). The study finds that occurrence of non-passenger vehicle (e.g., bus, heavy duty vehicles (HDV), trucks) effects in an increase in PM concentrations of between 30% to 40% compared with average of relative to the average pollution levels in ambient air. In addition, during high traffic situations (i.e., traffic jams, red light traffic) the PM level can increase by +47%. Locally, green spaces such as parks or gardens show 22% lower PM concentration levels than average (von Schneidemesser et al. 2019). In terms of urban heat stress, different urban layout, objects, or atmospheric conditions influence the perceptible temperature. Tree shadow or proximity to a water feature will locally reduce the temperature while high amount of concrete will increase the temperatures. Furthermore, during the heatwaves when the increased amount of energy is taken up by Air Conditioning that serves as a heat pump, pumping outside heat from air. In effect, local and city-wide levels of heat stress can increase.

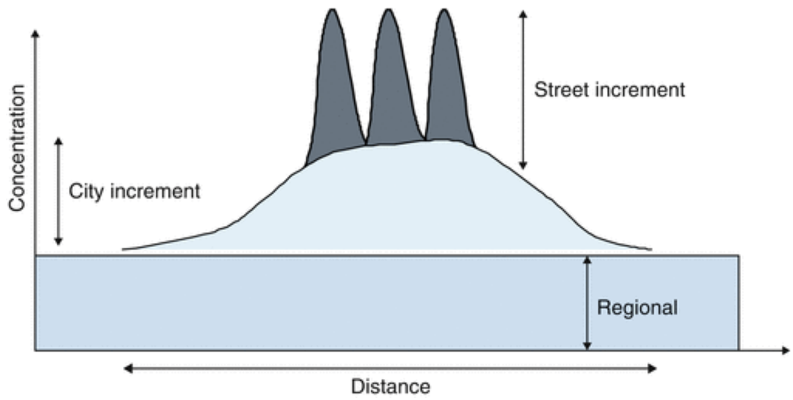


Fig. 13. Urban Air quality. City cross section. Illustration of air pollutant contribution. (Source: Goodsite and Hertel, 2012)

Population density with the relation to air quality and heat stress

While urban areas ensure economic prosperity and proximity to services, it comes at a certain cost. Scientific research talks extensively about the air pollution and urban heat in the cities, it is hardly linked with urban density (Borck and Schrauth 2021). The effect of urban heat stress and air pollution in urban districts is directly correlated with urban density in built-up areas that leads to increased temperatures city-wide, higher energy consumption rates and strongly impacts inhabitants health and liveability (Chun and Guldmann 2014). Over the last decades, urban air pollution has become a serious threat for citizens health being a key determinant for the development agenda. Brock & Schrauth have analysed urban density trends with the correlation of urban pollution indicating the economic costs of agglomeration. The study concluded that higher urban population density negatively influences local air quality (Borck and Schrauth 2021). Other studies found a statistically significant strong positive correlation between urban density and exposure to ambient air pollution. The air pollution parameters (PM 2.5, Co2, NO2 etc.) tend to increase while O3 is reduced. What is more, the costs of local air pollution are larger than the environmental benefits (i.e. Co2 reduction) due to dense living (Borck and Schrauth 2021; Carozzi and Roth 2020). Research has found a significant correlation ($R2 > 0.95$) between high urban population density where the impervious areas are dominant and mean surface temperature (Chun and Guldmann 2014).

Sustainability

This section discusses the Sustainability Development Goals (SDG's) that respond to the earlier outlined urban problems and describes how the proposed IoT technology can improve sustainability in urban areas.

To ensure high urban living quality with economic development and environmentally sound practices, sustainability plays a key role in development. The concept of sustainability has been introduced and commonly accepted back in late 1980s (Brundtland 1987). Sustainability is based on three pillars: society, economy, and the environment. Global efforts to address the sustainability are most accurately assessed by UN's 17 Sustainable Development Goals that address full spectrum of issues the humanity is currently facing (UNDP, 2015). Out of the 17 SDG's this research aims to address three of them outlining four improvement points in the city (Fig.15).

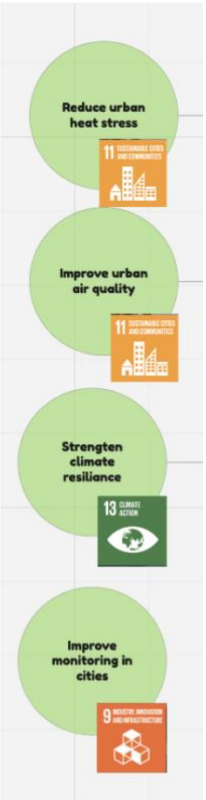


Fig. 15. Defined urban goals for cities

Goal 9 "*Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation*" can be linked with improving monitoring in cities. Goal 11 "*Make cities and human settlements inclusive, safe, resilient, and sustainable*" answers the questions of reducing heat stress and improving air quality. Goal 13 "*Take an urgent action to combat climate change and its impacts*" relates with stronger urban resilience to the changing climate.

Fig. 14. Addressed Sustainable Development Goals (UNDP, 2015)

The concept of *sustainable city* mentions that the consumption of resources in urban areas does not exceed the resources provided by the environment including water, soil, energy resources and that the urban pollution does not overpower environment's capability to provide resources to the ecosystems (Belli et al. 2020). Previous sections (i.e., Chapter 2: Background) indicated a major global problem of maintaining urban sustainability at many levels. This together with the effects of climate change – partially triggered by cities' activity – has attracted wider academia attention and caused appearance of intergovernmental and non-governmental global agreements and groups that aim at mitigating the negative effects of urbanization and climate change in the cities. Groups like C40, Global Covenant of Mayors for Climate & Energy, UNEP, Carbon Disclosure Project to name few, to research and develop the solutions making urban areas more sustainable and climate resilient. Those international agreements pressure and motivate global cities to meet the sustainability targets assuming cooperation, knowledge sharing and innovation.

The development of ICT enablers morphing power in the fabric of contemporary cities providing new opportunities to improve the way cities function in a more sustainable way. Meeting the outlined four improvement points in the city will increase the sustainability levels in the following ways: Heat waves trigger higher usage of Air Conditioning (A/C) units which to be operating need vast amounts of electricity funnelling heat outside which contributes to the effect of urban heat island. Moreover, the increased need for electricity is linked with the increased energy production which contributes to higher levels of CO_2. Better mitigation of temperatures leads to comparable lesser CO_2 emissions and lower urban temperatures. Secondly reducing air pollution in the city will improve the health of the inhabitants and the condition of local environment. The appropriate measures against climate change will address the economic performance as the city will be better prepared to address coming challenges and improving wellbeing of the society and the environment.

Strategies for measuring Air Quality and Heat Stress, and National Standards

The following section outlines the current methods of monitoring air quality and temperatures in the Netherlands mentioning the national standards for air pollution and studies on heat stress answering the research sub-question:

- *What are the policies that define limits to HS and AQ in the Netherlands and how are they informed?*

Air Quality

It is crucial to monitor the urban parameters to assess the extent of pollution in given urban regions and to inform the public about the environmental trends in the cities (i.e., air quality, heat, percentage of greenery, vehicular movement etc.). Detail air pollution information helps cities implement goals and standards, evaluating the existing environmental models and assessing the effectiveness of the implemented strategies. Therefore, data availability is key enabler to accurately measure the impacts of air pollution and heat stress on the society (EPA, 2019).

Fixed stations & Remote sensing

Monitoring of atmospheric pollutant compound primarily was performed using the optical analyses which are bulky, not easy in use and very expensive (e.g. starting from 5000 £) (Chong and Kumar 2003). Fixed monitoring stations are commonly provided by governmental authorities. The conventional methods provide an extensive overview of the pollutants and reliable data. This measuring techniques can ensure long time and reliable pollution overview. Despite that, due to limited number of fixed monitoring stations low spatial resolution of data is displayed and it is not possible to accurately assess the different pollutants level on the local level (Xie et al. 2017). Recent advancements in the field of air quality sensing has effected in more compact less expensive sensors, although the limitations still exist in terms of widespread use and multi-point sampling (Kumar et al. 2015). Additional research is recommended to capture distribution of air pollution more accurately in the cities.

Remote sensing i.e. 'a technique for collecting information about the earth without taking a physical sample of the earth's surface or touching the surface using sensors placed on a platform at a distance from it' (Lim et al. 2009) has been implemented widely for environmental application studying (e.g. air quality, temperatures and water quality). The technology includes mounting a sensor on a satellite, on a plane or airborne structure. The sensor measures the energy reflected from the earth displaying the information as image (digital or photography). While remote sensing is used for measuring air pollution or temperature trends on a regional scale it has a relatively low resolution (Xie et al. 2017) and is additionally affected by tropospheric anomalies (Lim et al. 2009) being a sum tropospheric aerosols that create an optical atmospheric effect. Accounting for the change in radiation is problematic because atmospheric aerosol distributions vary in type, size, and its spatial temporal distribution. Low spatial resolution together with inability to precisely define the amounts of the pollutants makes satellites unsuitable for local monitoring of air pollution. The gaps in satellite monitoring are usually corrected by air pollution models that describe simulate the atmospheric condition. Geographical Information Systems (GISs) applications in air monitoring are necessary to determine the hotspots. The combination of GIS, remote sensing and air quality models delivers a stable base for regional air quality assessment. Although limitations exist, most often data needs to be compared with land reference point (i.e., sensing station).

National Standards

The concentration of the pollutants in the Netherlands has been reduced over the past few decades. Even though the industry and traffic have become less polluting, the air pollution in the Netherlands still impairs public health to some extent. Currently the Netherlands must comply with various air quality standards. Among others, the most important is the chapter 5.2 (Environmental quality requirements) of Environmental Management Act /Wet milieubeheer on air quality requirements. The document defines air quality standards, based on European directives (EU Directive 2008/50/EC which is implemented to reduce air pollution in Europe.

The Dutch limits on pollutants must comply with WHO standards while defining limits for NO_2, PM_{10}, $PM_{2.5}$. (Rijkswaterstaat, n.d.)

To achieve the indicated goals, RIVM which is responsible for accurately monitoring and informing citizens about all aspects of air quality in the country, monitors air quality, using the national Air Quality Monitoring Network (Fig.16). As of 2018, there was 60 permanent monitoring stations cross country. This data is used as an input for air quality models that can assess the current condition of the air pollutants.

Nevertheless, the concentration of air pollutants varies on a local scale depending on the pollution sources (e.g., streets, industries etc.). Data collecting stations are placed not densely enough and need to be supported by models that are used by RIVM to fill the gaps in data. Additionally, Environmental Management Act 5.2 outlines that monitoring program is an obligation. National Air Quality Monitoring Program (NSL) was set to monitor and assess and report the air quality condition. It consists of a collaboration between the organizations RIVM and Rijkswaterstaat Living Environment.

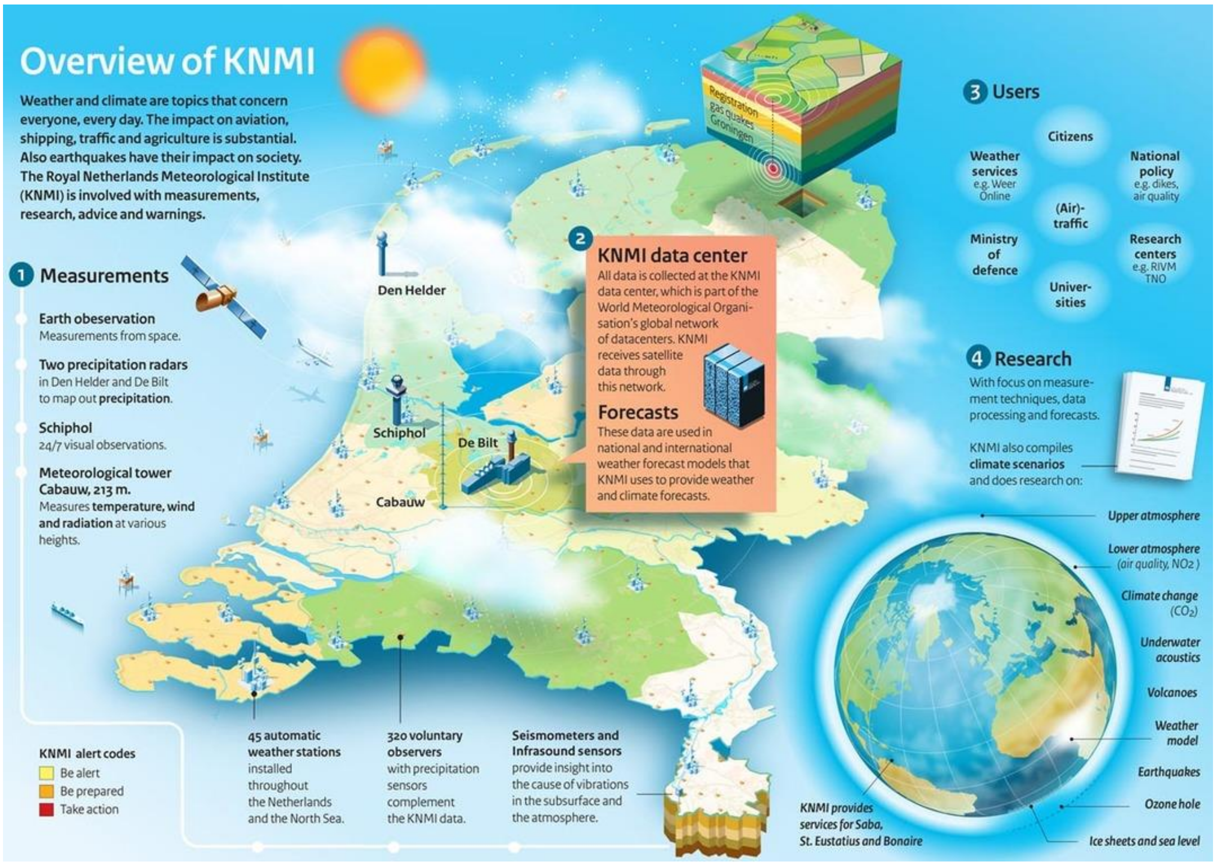


Fig. 16. Overview of KNMI weather and climate monitoring system.

For more detail data municipalities install air quality and temperature sensors independently. As an example, City of Utrecht has currently 32 air quality sensors operating on LoRa

Telecommunication Access Technology with the data frequency every 3 minutes. Utrecht plans to expand the measurement techniques placing 60,000 smart lampposts in the future (Manolopoulos, 2019).

City	City aspect	Amount	Monitoring	Sensor type	Telecomunication Access Technology	Transmition frequency	Plans
Utrecht	Air Quality	32	PM10, PM 2,5, Temperature	Particulate Matter Concentration Sensor & Thermometer	LoRa	3 mins	60,000 smart lampposts

Table 4. Example of Air Quality monitoring system in Utrecht (ibid)

Urban Heat Stress

Both surface and atmospheric heat is important to accurately describe the temperature patterns. When describing societal temperature comfort the most important is to measure accurately the atmospheric temperature that can be found in Urban Canopy Level (UCL). Air temperatures found in UCL serve as temperature indicators that help government to monitor and mitigate health risks. The air temperature can be measured directly by weather stations and other monitoring devices but also, by mobile devices placed in the vehicles along fixed routes which can be combined with GPS coordinates to better map the temperatures cross city. Nevertheless, mobile method cover only designated parts of the urban districts cannot provide a full spectrum of the city. The collected data can be paired with urban city models to estimate the temperatures in rest of the urban places where the field data is not obtainable (EPA n.d.). Typical blend of temperature information is provided by satellite data for surface urban heat island (SUHI) and data from surface monitoring with urban air models represent city's heat island.

Remote sensing allows to retrieve information about SUHI which can serve as a basic data input for retrieving air temperatures in UCL nonetheless this technique is far less reliable than direct measurements (EPA n.d.; Icaza 2017). While air quality pollution is a common urban problem considered by international policies and action plans, heat stress has played negligeable role in the past due to geo-location of the Netherlands and its mild climate. Nevertheless, climate change effects and increasing number of heatwaves, prolonged longer summers have urged the Dutch government to consider heat stress as nationwide issue that needs to be tackled. RIVM has prepared a National Heat Plan to be implemented during heatwaves. RIVM has prepared a map displaying Urban heat island (UHI) effect in the Netherlands. This map shows the urban heat island effect, which is the summer average air temperature difference between urban and surrounding rural areas. The map displays the heat hotspot's locations to inform the responsible parties where to take measures and clearly displays that, cities have significantly higher temperatures than the rest of the country. Map's resolution varies between 100 to 250 meters and is based on a UrbClim model that works with annual average temperatures which makes it unsuitable for extremely hot summer days or nights.

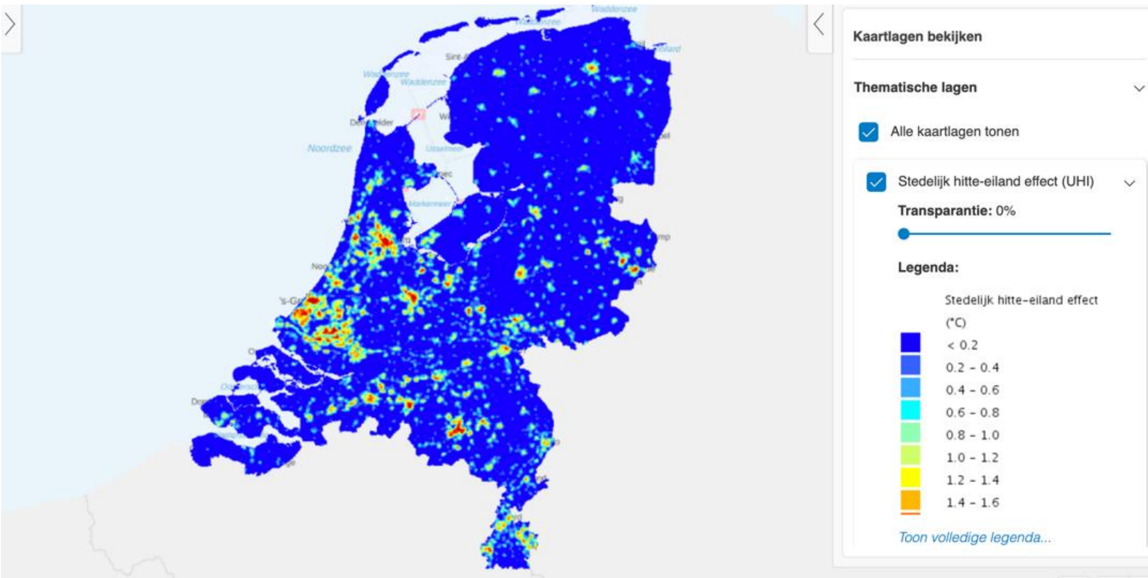


Fig. 17. RIVM hittemap of The Netherlands delivered from Atlasleefomgeving (2021)

Air Quality and Heat Stress monitoring in Rotterdam

For Urban Heat Stress there are no national standards for Dutch cities. It is up to individual municipalities to investigate heat stress and come up with mitigation measures because each urban form differs from each other having different hotspots for heat. The city of Rotterdam does not have a city-wide policy for reducing the urban heat. A study has been conducted in 2011 mapping heat stress in Rotterdam where the heat stress was measured in three ways:

- by means of simulation models
- by measurements using the mobile measuring unit (cargo bike) in and around the city centre
- by measurements using a measuring cable along, over and in the Westersinge

Modelling was done using the Envi-met model which simulates interactions between soil surface, buildings, vegetation, and atmosphere in an urban environment with a typical resolution of 0.5 to 10 meters. The study (Nijhuis 2011) suggested that street trees have the highest cooling capacity. Nevertheless, model did not calculate the thermal comfort but focused on the effect of the heat-limiting measures on the air temperature. It was highlighted that the interpretation of the results relates to a very specific street pattern, the building structure, the water temperature of the water channel and might differ temporarily. Therefore, the research has certain data gaps that could potentially be improved by using sensor technology. Additionally, during the research a mobile unit (cargo bike) was present and mapped the distribution of heat in the city. The mobile unit mapped the heat at a street level showing heat differences along different routes during the day and at night. Nevertheless, the data gathered was limited to certain time, specific day and only to the certain streets. The spatial and timely is highly restricted and the data received can serve as an input to the models but. Cannot serve as a strong informative basis for mapping the heat bearing in mind different factors (Nijhuis 2011). Another study considered remote sensing that displayed the temperature differences in 15 summer days since 1984 by satellite images retrieved from Landsat. The study showed that surface temperature difference in Rotterdam can be higher than 10◦C compared to surrounding non-urban areas. The temperature variables are visibly inconsistent per district, the satellite images and have the spatial resolution 60 by 60 m in (Landsat Enhanced Thematic Mapper) of the thermal infrared band of the visible and near-infrared bands is 30 m for satellites and programmed to have a revisit time of 16 days (Klok et al. 2012).

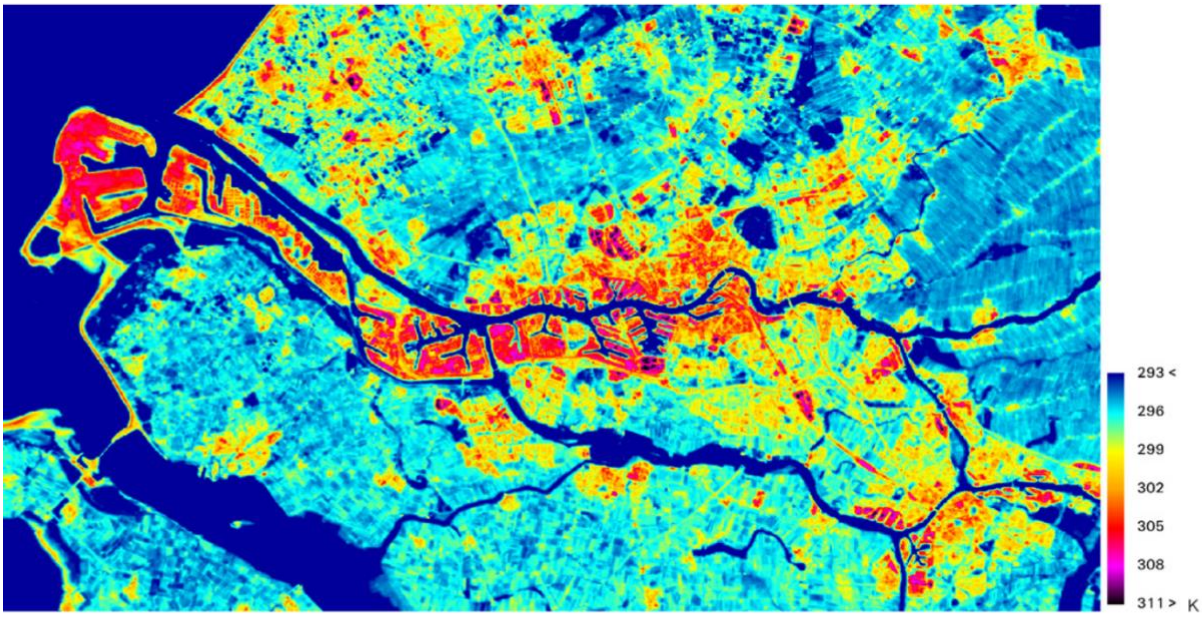


Fig. 18. Average surface temperature distribution (K) of Rotterdam based on 15 Landsat images (Klok et al. 2012)

At present, 13 basic air quality stations are present in the Rotterdam area (operated by RIVM-DCMR), mostly focusing on inner-city air quality (street stations). Rotterdam is currently implementing a citizen-based program for monitoring air quality De Luchtclub run by collaboration between RIVM and DCMR. While the goal is to deploy 800 sensors, 27 sensors have already been placed that could be displayed on a real-time map: samenmeten.nl.

Website	**Variable**	**Number of sensors displayed**
Luchtmeetnet	PM2,5	10
DCMR/RIVM	PM 10	11
	NO2	11
	Temperature	0
Atlasleefomgeving	PM2,5	Global information not specific to sensors informed by models and remote sensing
	PM 10	
	NO2	
	Temperature	
De Luchtclub	PM2,5	27
(yet to be implemented)	PM 10	26
	NO2	3
	Temperature	13

Table 5. Sources of information about air quality and temperature in Rotterdam (for further details see appendix table 5&6)

Chapter 3: Digital environment - Case study development

Previous sections of this report cover the main problems, limitations, and opportunities improving urban factors, mentioning status quo of the monitoring systems and policies that regulate the limits for pollutants. It became apparent that better ground monitoring of the urban areas is analytically important and novel technology enables more advanced monitoring methods. This section presents the concepts of digital infrastructure that help improve environmental parameters in the cities. Additionally, this section will introduce case study of a company that is a key actor providing IoT connectivity for Rotterdam - KPN.

The second part of the chapter will evaluate the selected case studies, exploring smart initiatives that advance urban monitoring of air quality and heat stress. Later, the key case study will be analysed through the prism of the smart initiatives that are already in place. The key take-aways from case studies will be determined and analysed through the Rotterdam example. This section aims to answer a question:

How can IoT solutions for monitoring help bridge the identified data gaps towards desired future state and what are the examples of implementation?

Smart Cities

Rapid development of ICT technology that help mitigate the beforehand mentioned problems in the cities has been indicated by many (Albino, Berardi, and Dangelico 2015; Höjer and Wangel 2014; Kramers et al. 2014; P. Singh et al. 2020; S. Singh et al. 2020). The development of such technologies is predicted to have a significant impact on the "*smart city*" paradigm which is continuously evolving (Belli et al. 2020). Some describe smart city paradigm as "*a well-defined geographical area, in which high technologies, such as Information Communication Technologies (ICT), logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development*" (Dameri 2013). Smart cities make use of data and digital technology to improve the quality of life. The solutions, such as real-time data monitoring, make different actors able to oversee the events as they unfold and analyse the supply and demand pattern, with much faster and more economically sound responses. Smart city technology can help limit the cost of gathering various information. The unprecedented volume of data helps actors (governments, companies, and residents) see-through the system and optimize existing operations. Moreover, the smart city can actively respond to the current factors shaping it the urban environments automatically (i.e., encourage residents to reduce the energy use, travel off-peak etc.,). Smart city assumes a more liveable place but also a more productive, optimised and efficient area for business operation (Woetzel et al. 2018).

Smart Sustainable Cities

Some criticize smart cities concept for being too technocratic and mostly driven by tech-companies' best interest, not considering citizens' best interest or omitting environmental sustainability aspects (Belli et al. 2020). Alternatively, a novel paradigm of cities that are technologically-infused and include the pillars of sustainability has recently attracted wider attention (Estevez, Lopes, and Janowski 2016). The concept of Smart Sustainable City balances out the economic, social, and environmental interest maintaining high levels of digitalization focusing on continuous transformative process of the urban area. This concept assumes a robust engagement and collaboration between the stakeholders, improving citizens quality of life, enhancing socioeconomic development while respecting the natural boundaries of the ecosystem and protecting natural resources together with locally-defined priorities (Estevez, Lopes, and Janowski 2016).

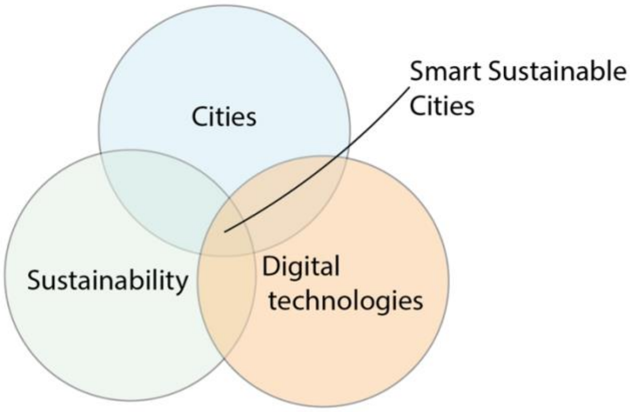


Fig. 19. Conceptual drawing of smart cities concept

Furthermore, a vibrant discussion in academic background has pointed out the digitally infused and sustainably aware cities as the frontrunners of the positive urban change in XXI century (Belli et al. 2020; Gubbi et al. 2013; Kramers et al. 2014; Liu 2018; Sarrab, Pulparambil, and Awadalla 2020; Song et al. 2020). Researchers suggest a high positive correlation between the implementation of ICT technology and the transformation of the cities across many domains of smart cities (e.g. smart energy, smart waste management etc.) (Bibri 2018b; Nižetić et al. 2020). This can be realized by research and development on different urban layers enabling technologies for collecting, processing, and analysing the diverse urban data. The prospects of IoT are clearly indicated by academia labelling IoT as socially disruptive technology that will deeply transform the techno-urban ecosystem in the future (Bibri 2018c).

Other studies take a specific focus on data monitoring and suggest that more detail and timely data monitoring can be achieved through development and implementation of ICT in urban tissue (Ahlers et al. 2018; Sun, Kato, and Gou 2019). Recent developments of low-cost sensors, available computing infrastructures and development and deployment of wireless communication networks that allows connecting various devices to internet enabling M2M communication create an immense opportunity to integrate the physical spectrum of the cities with digital technologies assisting new applications to advance environmental sustainability (Bibri 2018b). Different domains of the urban systems can be therefore integrated in line with goals and objectives of decision-making process. The predicted exponential growth of digital technologies (Bibri and Krogstie 2016) integrated with urban domain gives an opportunity and motivation for investigating the barriers and opportunities for improving the urban operational dimensions.

The sensor-based big data has been considered as one of the major drivers for advancing the environmental sustainability in the cities and what follows will help to meet different Sustainable Development Goals.

Internet of Things

The ongoing technological development has enabled new ways of connecting and integrating real world of things with the virtual world. Internet of Things (IoT) concept gained popularity at the beginning of twenty-first century. It is defined as: *'the interconnection of uniquely identifiable embedded devices, physical and virtual objects, and smart objects [connected to humans, embedded in their environments, and spread along the trajectories they follow] using the Internet Protocol version 6 (IPv6) [the new addressing infrastructure of the Internet with an unlimited capacity], embedded systems, intelligent entities, and communication and sensing-actuation capabilities'*(Bibri 2018d).

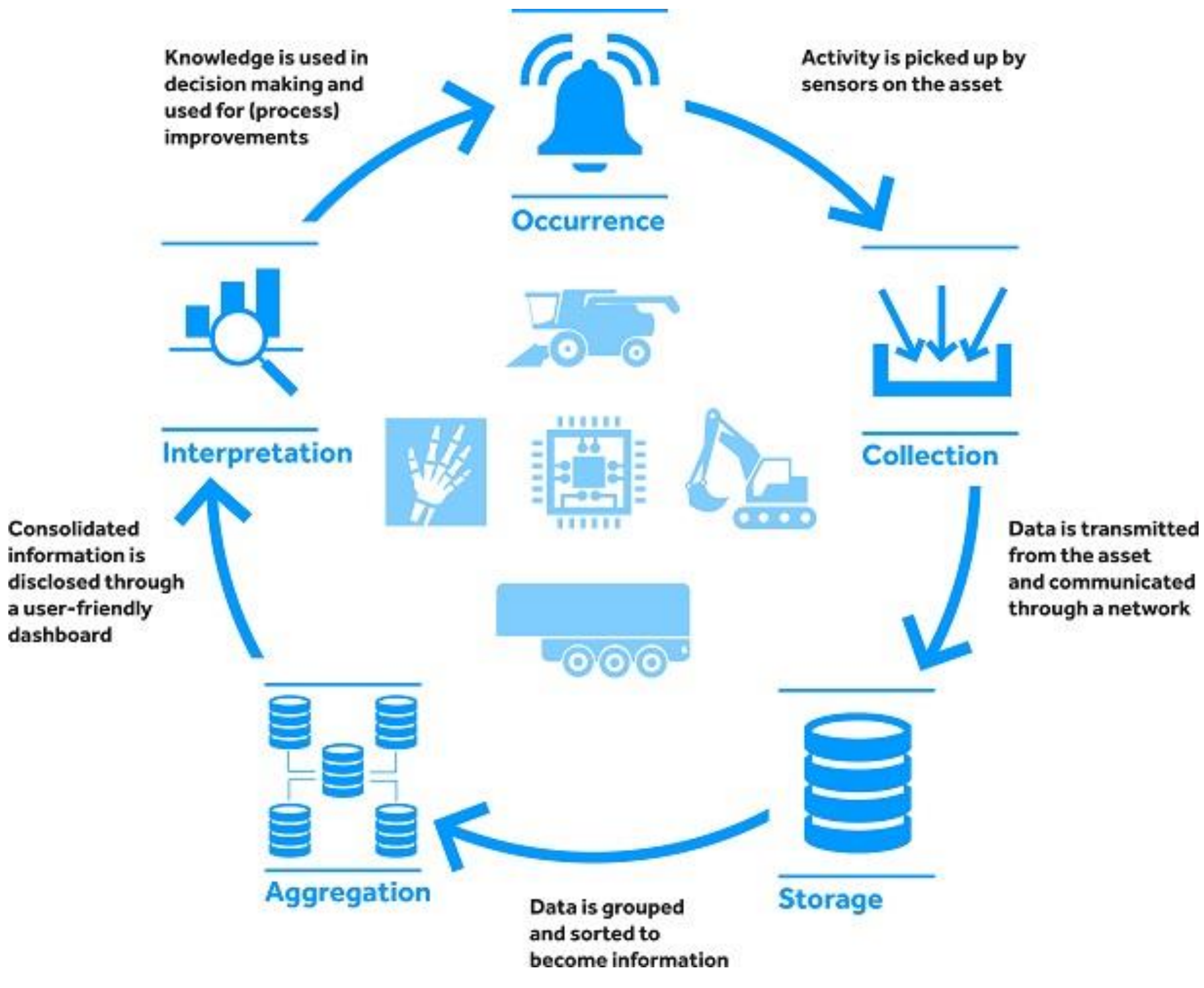


Fig. 20. Conceptual drawing of the IoT system (Source: DLLgroup,2021)

It assumes the absolute connection of things (i.e., smart technologies, sensors, actuators, modern communication methods) that have an inimitable identifier and can communicate over the wide-area network such as LoRa or any similar system (Evans, 2011, Uckelmann, et al. 2011, Liu, 2018). This wide-ranging use of various sensing technology delivers significant portions of data supplying a fine-grained digital perspective on the physical world. This concept characterises the 3rd wave of Internet development (i.e., 1st provided fixed internet connections, 2nd connected many mobile devices to the internet, 3rd connects plethora of different things to the internet where most of IP addresses belongs to objects). IoT concept assists M2M and H2M communication, allowing access to detail and densely distributed information and enabling management of the information at micro and macro scale enabling interest groups to act and plan the action. Sensory devices are the core of the data gathering in the cities, capable to sense the environmental conditions (i.e., humidity, stress, pressure, temperature, air pollution etc.) collecting the information of the phenomena and being able to communicate this information to network gateways where the data is processed. IoT can be used as a business tool allowing more efficient use of the resources and better management of business practices, IoT can also serve as a tool that betters daily life including home automation (e.g., AI Home Solutions - home security, smart lighting, and climate control products), waste management (e.g., Enevo - manage waste and recycling services), healthcare services (e.g., COMARCH – implementation of telecom and IoT solutions in medical area). While many start-ups are rising globally using IoT technology, this is still done on a small scale. When thinking about larger regions, the large scale and detail implementation of IoT and connecting large number of devices is still very complicated.

ICT and Smart Cities

Improvement of Air Quality and Heat Stress with IoT

As previously mentioned, current solutions for environmental monitoring rely on a small number of monitoring stations located in fixed sites. While the accuracy of such devices is high, the cost of the devices obstruct large scale deployment. Nowadays technology allows deployment of many modern sensors for a fraction of costs. The development of low-cost sensor technology that collects and measures data across urban domains is the basis for IoT enabled data processing. The automatization of routinely sensed data will reduce the human attention and will allow to automatically map the urban hotspots for various urban trends and factors. Deployment of sensors will especially help to map the hotspots of less obvious data (i.e., Air Quality & Air Temperature) on a very precise local scale and fill the data gaps in urban areas (Bousquet 2017; Kumar et al. 2015). The feasibility of monitoring solution supports denser deployment providing higher spatial resolution of data improving accuracy and affordability. The accessibility of sensors allows higher community inclusion and rise of community-led projects that will advance societal understanding of phenomena supporting governmental policies to improve air quality and reduce heat stress.

Even though it is predicted that the full transformation towards digitally-enabled cities will occur over the course of next 10 years (Bibri 2018b) the developments in the sensor technology currently allow to implement low-cost, miniaturized devices portrayed as high performance devices that are capable of delivering higher quality dense data. Considering the capabilities of technology, current academic and technological research with the relation to IoT is focused on designing and implementing a dense web of sensors in pilot projects. Experts predict that it's a matter of time until larger-scale implementation will occur globally (*ibid*).

Remote sensing of data can be linked with ground sensor data to better and timelier envision the existing pollutants in terms of spatial resolution. The air quality sensors have been measuring the air parameters for decades now. Until now the main limitation for dense implementation of the sensor network was its cost. Since 2010s the development of sensing technology that ensures feasible and more portable devices that precisely monitor the air quality trends has been growing significantly (Kumar et al. 2015). With the given data, policy makers can implement or adjust urban infrastructure decisions, reducing the societal exposure to pollutants or excessive heat delivering information in each location in real or near-real time. On top of that, what might be seen as futuristic, the appearance of interconnected digital systems correlated with the physical infrastructure of the city might help mitigate various problems (e.g., redirecting the traffic in real life, changing operation patters of powerplants, or sending real-time location-based warnings to those suffering from berating conditions) (GSMA,2018).

Role of Telecom & KPN case study

When considering the role of telecommunications networks in modern life, its key function is ensuring means of communication and networks. Some suggest that policymakers and scholars have overlooked the relationship between telecom sector and sustainability (Moss, Kaufman, and Townsend 2006) due to its indirect effects on changing patterns of mobility, land use, energy consumption etc.. The connectivity, provided by telecommunications, shifted the societal behavioural patterns and way of work and study vividly. The need for travelling is diminishing instantaneously replaced by virtual data. Being labelled as the nervous system of modern metropolis telecoms ensure that communications, business activities, government functions, information gathering depend on access to phones and internet. Apart from that, innovative use cases of communication technology allow to develop strategies that improve environmental sustainability on a local single building scale, district or urban scale, economy, government.

KPN

KPN (Koninklijke PTT Nederland NV or Royal KPN N.V.) is a landline and mobile telecommunications company that originated as an agency of the Dutch government in 1881 for the post, telegraphs, and telephones (KPN, 2020). In 1989 KPN became an independent company. Currently, the company is focused on digitalization concentrating on business-to-consumer (B2C) and business-to-business (B2B) markets. While B2C services include telephony, internet, and television, B2B additionally includes various end-to end solutions (*ibid*). This research focuses on B2B services that can be delivered by KPN to support smart initiatives deployment in the cities.

KPN has taken a leading role being named one of the world's greenest telecom companies implementing sustainability solutions in different operational aspects. To stay ahead of the competition KPN set far-reaching sustainability goals constantly reducing its impact on the environment. Since 2015 KPN's business is climate neutral. The next ambitious goal is to become 100% circular and by 2040 to be CO2 net zero in the entire value chain (KPN 2020).

Moreover, KPN actively works to improve the condition of the Dutch cities being actively involved in deploying B2B solutions that enable connectivity, data handling, IoT and sensor technology solutions for cities.

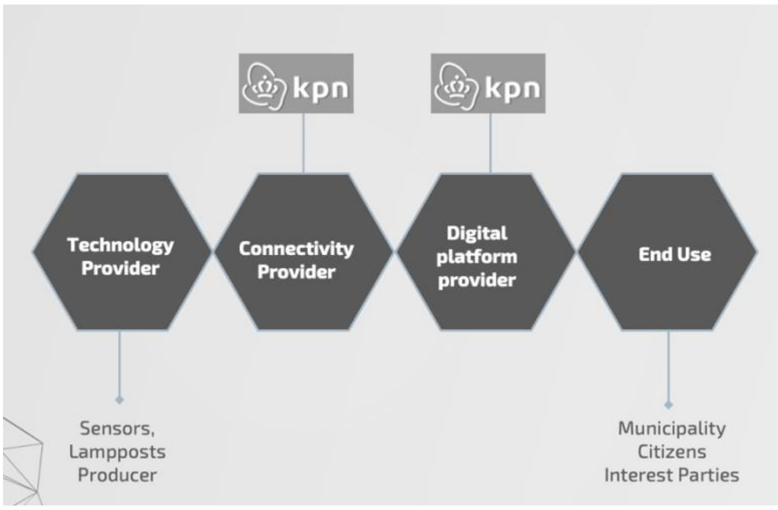


Fig. 21. IoT environmental monitoring chain for cities and role of KPN

Implementation of smart city framework is an exceptionally complex task involving actors coming from diverse backgrounds including technology, government, society, and economy. When considering implementation IoT monitoring systems there are four key actor groups considered: Hardware technology providers, Connectivity providers, Data management platform providers, applications for the end user. The telecoms can serve as the connectivity and digital services providers taking up the middle position of the IoT monitoring delivery chain.

In the Netherlands, KPN had been cooperating with cities like Rotterdam, Amsterdam, Eindhoven on many occasions to develop various smart solutions, ranging from smart streetlights, smart waste management, smart parking etc. Nonetheless, the smart solutions that

KPN was involved in each of the cities in were tackling issues like lighting mobility or energy flow, not considering aspects of air quality and temperature monitoring.

Since 2016, Rotterdam and its Zuidplein has been undergoing a smart city transformation. KPN as one of the leading partners in RUGGERDISED project was involved in delivering connectivity solutions for the city connecting sensors deployed in various places (i.e., waste containers and parking spaces) with LoRa network. KPN's infrastructure and connectivity services provide a foundation for further development of the vision and can be further expanded for not only delivering the underlying connectivity services but also being a key actor for implementing data management platform that displays the data in apps for the end users.

Connectivity

Each smart solution needs a connectivity network to enable the M2M communication creating a significant opportunity for IoT technology to optimize services and business processes. Connectivity networks have been gradually implemented by KPN since 2016 cross country giving the possibility of further development of IoT technology in different places in the Netherlands. As of today, KPN's IoT connectivity portfolio includes: LoRa, LTE-M, 4G/LTE.

LoRa (Low Range) is a network modulation technique derived from Chirp Spread Spectrum (CSS) technology that ensures energy efficient and financially viable solutions for cities. The network is meant for equipment that does not constantly need its own internet connection. When monitoring air quality and temperatures, comparatively small amounts of data are transmitted to the cloud. LoRa network is the best suited for IoT applications where devices regularly exchange small amounts of information and therefore is the most feasible network for monitoring air quality and temperatures in the cities. Its battery life can last as much as 15 years using just two batteries. Moreover, LoRa can also localize the objects within the accuracy between 50 and 150 meters which can also be a solution for mobile sensing technology (i.e., buses or bikes). It's simple construction (Fig. 22), makes the solution a relatively cheap network for M2M communication.

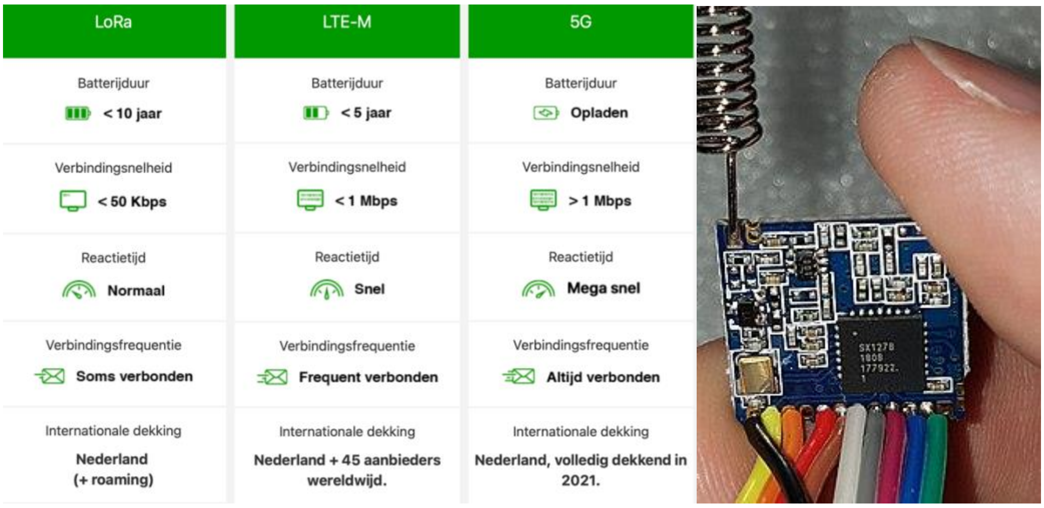


Fig. 22 comparison of the IoT networks and LoRa module. Source: KPN (n.d.)

LTE-M network is a type of low power wide area network (LPWAN) radio technology enabling communication of cellular devices and services (M2M and IoT). LTE-M is a technology where a lot of data is exchanged with great regularity. The network is a more expensive solution that requires more bandwidth, compared with LoRa. For the measuring techniques of air quality and temperatures that are proposed in this research, LoRa seems to be a more viable solution. Nevertheless, the system proposed in this report aims at a constant development and improvement of the features in the system. There is a possibility that due to the information flow, future extensions of the system will have to be supported by more advanced networks (i.e., LTE-M). Further research is advised in this matter.

In terms of digital platform development, KPN has been developing B2B solutions for IoT deployment namely, KPN Things. This service offers four flexible building blocks (Fig. 23.) to build a complete IoT solution. The system is scalable and flexible. Nonetheless, despite some smaller scale implementations (e.g., Happen Containers), KPN Things has not yet been implemented on a larger scale (i.e., city scale). Another IoT solution developed by KPN is Data Service Hub which is platform-as-a-service for real-time information exchange for businesses. The platform enables display of the collected data and its exchange between multiple user groups. Both solutions create a base for further development, advancing the services to make it suitable for big scale IoT monitoring services and if further adapted and expanded can be implemented in the cities.

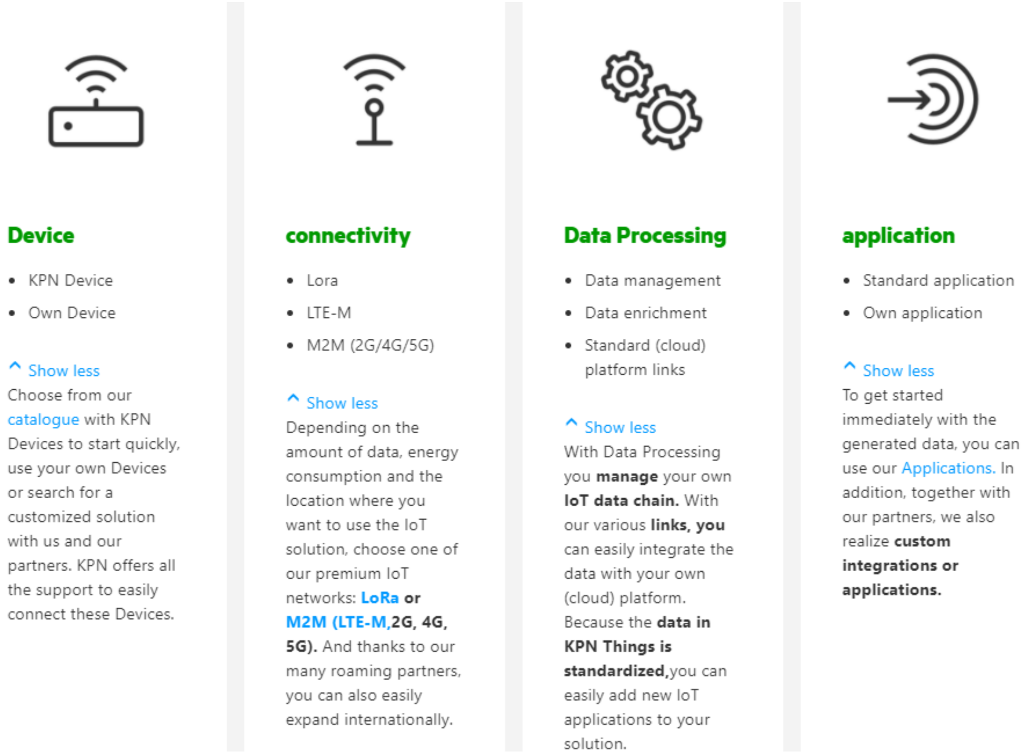


Fig. 23. KPN's IoT products

Chapter 4: Case studies: selected cities with smart initiatives.

This section discusses the case studies that will serve as the global benchmark of implementing IoT solutions for air quality and heat monitoring.

This section aims to answer the following research sub-questions:

- *Which cities are relevant to compare with the case city Rotterdam and why?*
- *What are the key generic barriers and opportunities strengths and weaknesses for implementing the IoT technology in case studies?*
- *What are the barriers and opportunities strengths and weaknesses of smart initiatives in Rotterdam?*
- *What lessons can be learned from these international reference cities and how can the lesson learned be implemented in Rotterdam?*

This section aims to compare four global cities examples (i.e., Barcelona, Chicago, Copenhagen, Singapore) that have implemented digital technology into urban tissue to improve the city's performance and environmental sustainability. The case study selection includes Barcelona (Spain), Chicago (USA), Copenhagen (Denmark), Singapore (South-East Asia).

The selection was based on the given factors: population and area size, geolocation, existence of air quality & heat problems in the city, different objectives for implementing IoT technology, and initiatives. The international case studies were chosen deliberatively to be comparable with Rotterdam, also to deliver diversity of solutions and differencing factors (different population size, geolocation).

Case Study	Location	Population Size	Area
Barcelona	Europe (South)	1,62 m	101,9 km^2
Chicago	North America	2,71 m	606,1 km^2
Copenhagen	Europe (North)	600 000	88,25 km^2
Singapore	Southeast Asia	5,7 m	728.3 km^2
Rotterdam	Europe	651,157	325.79 km^2

Table 6. Comparison of Different Cities (OECD, 2020)

Selection criteria:

According to OECD, "*Urban areas are classified as: large metropolitan areas if they have a population of 1.5 million or more; metropolitan areas if their population is between 500 000 and 1.5 million*" (OECD, 2020). The selection of case studies includes three large metropolitan areas (Barcelona, Chicago, Singapore) and two metropolitan areas (Copenhagen and Rotterdam). Diverse urban population as well as diversification of the metropolitan areas both aim to better envision different barriers and opportunities for implementing smart strategies. Different geographic zones (Asia, Europe, North America) aim to compare diverse practice for implementing the smart strategy. Moreover, most of the chosen case studies have a comparable role: Barcelona (second in population size, after Madrid) as well as Chicago (third – after New York and Los Angeles) and Rotterdam (second after Amsterdam), serve as the regional capitals being the second or third biggest city in the country. Copenhagen, located in Northern Europe is the smallest case study, and has the advantage of being regional capital for smart solutions acting as pilot city for implementing smart city concept. Singapore was named the smartest city in the world due to its advanced technology, digitalization, and progressive smart projects in place. Major advantage of Singapore is its city-state status that allows to implement the smart solution nation-wide on a large scale.

Additionally, each of the case study implements the smart city initiatives being driven by different objectives. Barcelona is introducing smart technology for benefit of citizens, putting the society as principal's benefice of the implemented solutions. Chicago aims to digitalize society and business, bridging the gap between different minorities, engaging the society in the smart city initiatives. Copenhagen on the other hand implements IoT solutions as a key enabler for achieving the climate neutrality goals by 2025. Therefore, smart initiatives in Copenhagen are mostly focused on energy exchange projects and data sharing. Singapore as a one of the most advanced smart cities introduces IoT technology cross various disciplines and city-wide.

Singapore's ambition is to stay ahead of the smart city competition and to improve lives and livelihoods for all.

Furthermore, all case studies have implemented an agenda for realising environmental monitoring with IoT sensor base. Each reference study displays different ways of approaching the topic of heat and air quality monitoring experiencing the pressure of air pollution and heat stress within the city boarders.

Identified problems in case studies:

The selection of case studies embraces the cities that recognized a shortage of mitigation measures for urban air quality or heat stress.

Case study	Air Pollution	Main factor	Heat Stress	Main factors	Reference
Barcelona	X	Traffic*	X	Old infrastructure, Amount of surrounding greenness, some N-S street positioning, A/C	(Ingole et al. 2020)
Chicago	X	Traffic	X	Concrete	
Copenhagen	X	Residential wood burning, Traffic	X	Old infrastructure	(DEC 2014) (Copenhagen Urban lab, 2019)
Singapore	X	Industry	X	A/C, local humidity levels	CNA (2019)

Table 7. Outline of the problems in identified in case studies (see Appendix Fig 2, 4)
**(interview with Jordi (Appendix [6])*

Barcelona is an example of a city that due to its geolocation experiences relatively hot summers and mild winters. Various studies indicated the relationship between heat stress and urban morality rates (Xu et al. 2013, Ingole et al., 2020) in Barcelona showing that 6 out 10 districts are subject to societal heat-mortality risk during the summer season. Moreover, the city of Barcelona expects increased frequency and intensity of heat waves due to climate change (Salama, 2014). Furthermore, taking 2018 as the example, air pollution was responsible for 351 premature deaths in urban district as Barcelona Public Health Agency states (ajuntament.barcelona, n.d.) and is one of the most NO2 polluted cities in Europe reaching 38,9 annual meanwhile 40 µg/m^3 is recommended by WHO (Khomenko, 2021).

Copenhagen faces certain levels of air pollution as well as heat stress. With the temperatures reaching up to 47 degrees Celsius the urban heat stress is distributed not evenly in the city (Copenhagen Urban lab, 2019). Moreover, the city air pollution is not neglectable. Yearly, as of 2013 between 500-600 premature deaths were accounted in Copenhagen – see appendix 2. Fig 2. (DEC 2014).

Chicago is ranked 18th most polluted city in the USA in ozone-pollution (lung.org 2019). Additionally, fine particulate matter pollution remains among the highest in the nation. Yearly, 5% of premature deaths in Chicago is linked with high levels of PM 2.5 (City of Chicago 2020). In some location, Chicago has lower evident heat stress (surroundings of Lake Michigan due to its cooling effect), but overall, a significant urban heat stress is observed in central locations of the city (Alfraihat, Mulugeta, and Gala 2016). When compared with other Asian capitals, Singapore's air quality is good and could be compared to European standards. In 2019 the PM 2.5 concentration average for Singapore was 19 $\mu g/m^3$, exceeding WHO recommended target of 10 $\mu g/m^3$(IQAir,2021). Main reason for lower air quality in Singapore is industry operation (i.e., shipping, refineries operation, etc.). The city-state has multiple policies in place to improve air quality. Singapore's geolocation indicates extremely hot and humid temperatures. This puts Singaporean society at risk of heat stress. Moreover, due to the humidity levels, Singapore appears to warm up 0,25 C per decade - which is twice as fast as the rest of the world due to climate change (CNA, 2019).

The indicated urban problems in each case study are mitigated in various ways. To monitor and alleviate the urban stressors, each case study implements initiatives that use ICT on a different scale and in a different manner. The following section outlines the smart city initiatives that include ICT solutions for urban stressors data monitoring.

Barcelona Digital City (2015-2019)

One decade ago in 2011, following the EU strategy to create more sustainable smart cities (alongside with SDG11) Barcelona has launched smart city policy creating project a 'Digital Agenda for Spain'. This 170€ million digital city project was investigating and advancing technologies like 5G, interoperable virtual labs, smart tourism, public services platforms. From 2015 onwards, Barcelona is directing its actions towards Smart City approach. Barcelona Digital City project is focused around 3 themes: Digital Transformation (*Technology for better government; Urban Technology City; Data Commons*), Digital Innovation (*Economia digital; Make in BCN; i.lab*), and Citizen Empowerment (*Education and digital skills acquisition; Digital inclusion; Democracy and digital rights*) (Ajuntament.barcelona, 2015)

A part of digital transformation project Barcelona has deployed a dense network of sensors called **Sentilo** project. The project aims to deliver various data coming from more than 19.822, active sensors spread across the city complying and sharing the real time data from a wide variety of sources. The sensors are facilitated with a various set defining 10 categories: Energy, Noise, Garbage, Parking, Air Quality, Water meter, Bicycle flow, People flow, Vehicle flow. The Sentilo project puts Barcelona in a leading position among other smart city projects providing a real-time information. The project is based on an open-source software and is displayed in spatial dimension using City OS. The platform is able to analyse the urban data, acting as an informative tool for the City Council. Basing on the input delivered, the city council can distribute municipal resources more efficiently and offer new data-driven services suited to the needs of city residents.

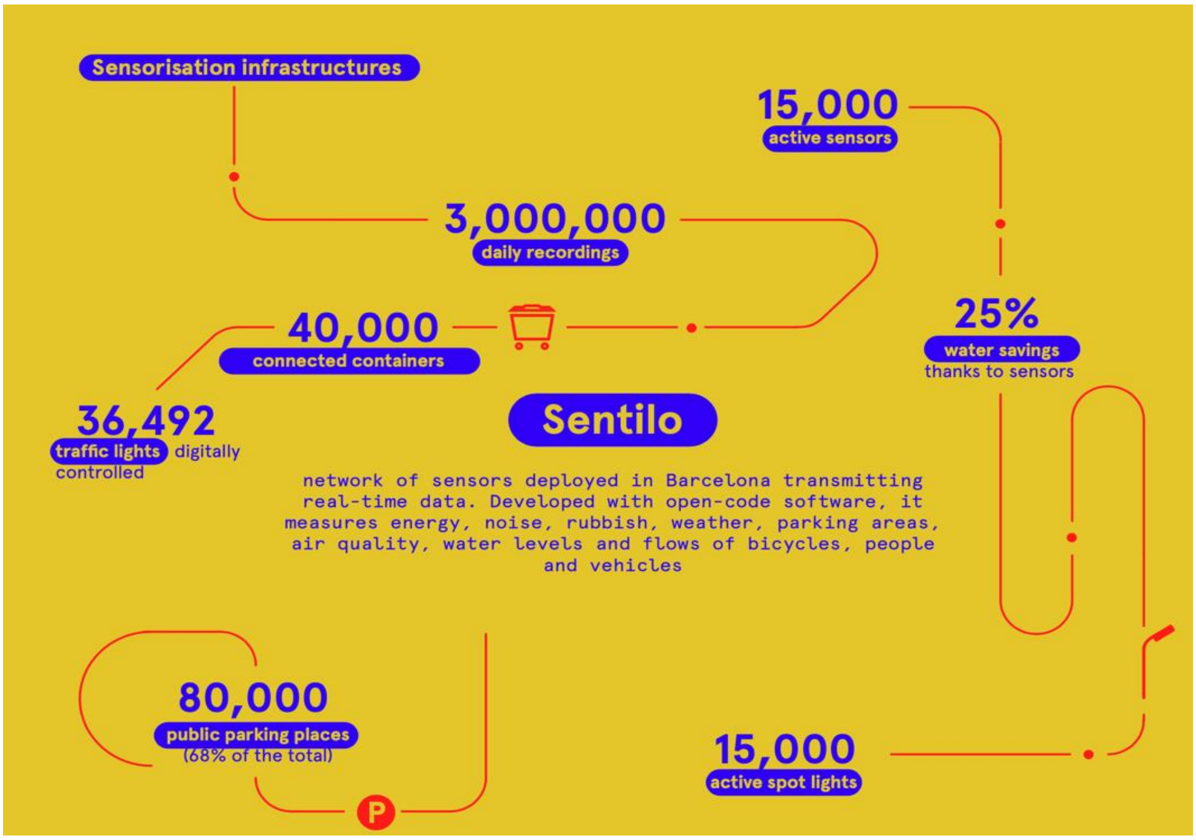


Fig. 24. Sentilo project display (the numbers have increased to 19 822 sensors)990

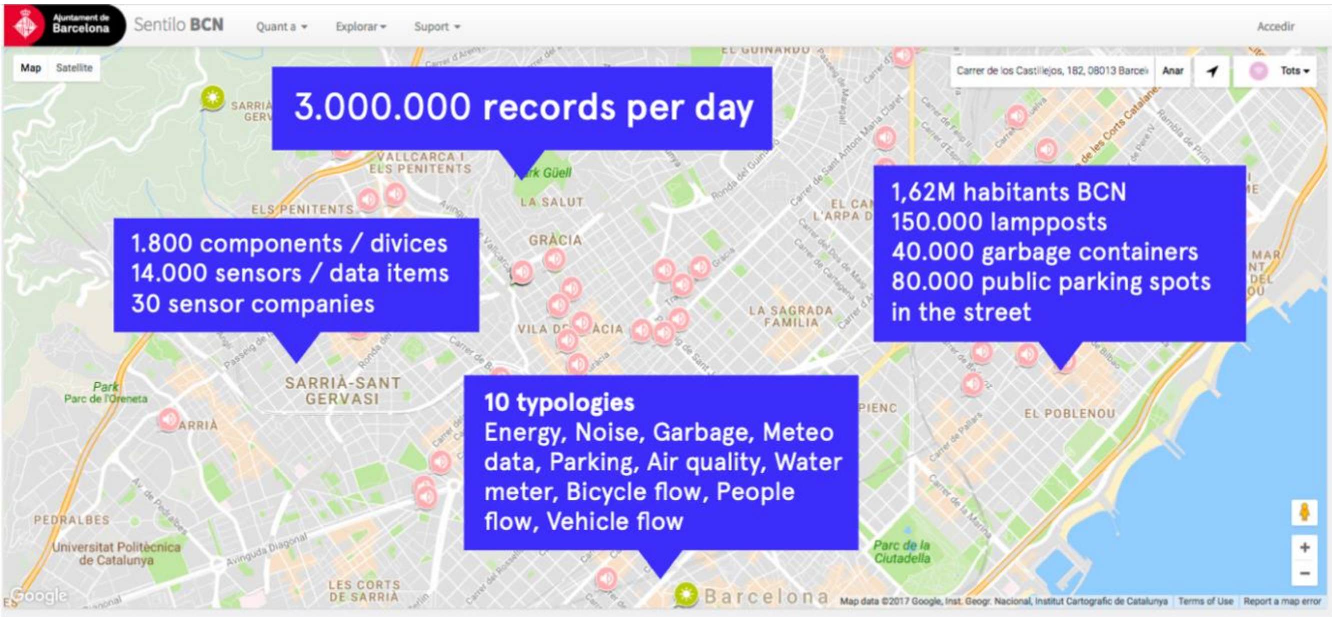


Fig. 25. Visualisation of sensors deployed in city area with context information. Please see the data visualisation available website at: http://connecta.bcn.cat/connecta-catalog- web/component/map#

The IoT technology implemented across the city of Barcelona helps to generate, collect, receive, catalogue, process and interpret a significant amount of information. The goal of the project is to create a public common-good resource for the society. The sensor technology allows one to see the key hotspots in the city and can be used for decision-making purposes to swiftly and democratically implement innovation and improvements to empower people. The Municipal Management Dashboard helps to map and display a datatrends in a well-defined manner explaining the state of the city in real-time. The combination of sensors and display dashboard facilitates monitoring and fasters a follow-up action public on policies that are being carried out in the city. Sentilo's most important drawback is its weak interoperability. It supports only the REST API and cannot communicate via other protocols which limits its communication flexibility between different devices (Bain 2014).

Barcelona

Strengths	Weaknesses
· Well-developed system that tackles various urban issues (Nižetić et al. 2020) · Easily accessible platform (Bain 2014) · Actual sensitization (interview*) · Awareness of population about air quality and urban heat (interview*) · Possibility of extending platform functions · The presence of a hierarchical and customizable item representation on a map (Bain 2014)	· Maintain its competitiveness and economic growth (interview*) · Lack of budget for further implementation of Smart City Strategy (interview*) · Weak interoperability (Noori, Hoppe, and de Jong 2020)

Opportunities	Threats
· The various systems can be connected to improve the air parameters in the city (e.g., traffic congestion) (interview*) · Expanding the system to neighbouring regions and cities (Bain 2014)	· Drastic changes in the IT international marketplace can deeply affect the economy (Estevez, Lopes, and Janowski 2016) · Due to wide societal inclusion inability to smoothly implement future projects based on data gathering

Table 8. SWOT Barcelona's Sentilo
(interview) – interview with Jordi (Ajuntament de Barcelona) Please refer to Appendix [6].*

Smart Chicago

Chicago is the most populous city in the state of Illinois and the third most populous city in the USA. Chicago introduced The Chicago Technology Plan in 2013. The plan presents initiatives that aim to realize Smart Chicago's potential, where technology powers opportunity, inclusion, engagement, and innovation for the citizens. The plan ensures implementation of five technology-focused strategies which together include almost 28 smart initiatives. Two foundational strategies include introduction of Next-Gen Infrastructure (A) and Creation of smart community (B). Growth strategies include more efficient and open government (C), civic innovation (D) and technology sector growth (E). Strong Mayoral vision for realizing modern city infrastructure, smart communities, and technological innovation, paired with sturdy collaboration between public and private parties creates an immense opportunity for Chicago. The initiative three of Next-gen infrastructure (A) aims to develop urban sensing collecting and using the data in public spaces recognizing the value of city data for decision-making purposes.

One project, especially focused on sensor deployment, is already being developed. "The Array of Things" (AoT) project consists of a network of sensors mounted on the sides of the building and traffic lights, collects real-time data on Chicago's environmental surroundings and urban activity including traffic patterns, air quality, temperature, vibration, monitoring up to 15 various phenomena. At the end of the project 500 sensor devices will be deployed in the city of Chicago. The system will deliver information about road condition envisioning traffic patterns, air quality, temperature, vibration magnetic fields and many more. Moreover, data platform is being developed in collaboration with private sector and educational institutions. As of January 2020, there was 130 nodes installed, nevertheless due to the COVID- pandemic the further deployment was put on hold.

Chicago

Strengths	**Weaknesses**
· Strong cross-sector cooperation to achieve smart vision (including WBC, SCC, Universities) (The City of Chicago 2013) · Diverse customer base (*ibid)* · City as a regional research capital (*ibid)* · AoT: advanced environmental monitoring system (Bousquet 2017) · Edge computing (Catlett et al. 2020) · Strong Mayor's Vision (The City of Chicago 2013)	· Limited amount of sensors (The City of Chicago 2013) · Deployment takes long time *(ibid)* · Expensive nodes *(ibid)*
Opportunities	· Threats
· Civic innovation (The City of Chicago 2013) · Reducing the price per node · To become main R&D centres in USA · Interest cross sectors to cooperate	· Lack of further funding

Table 9. Chicago's AoT SWOT

Copenhagen Connecting

The city of Copenhagen with about 600,000 inhabitants is the largest city in Denmark. Copenhagen is named one of the world's most liveable cities since it pays excessive attention to its inner sustainability. Its smart framework is primarily focused on tackling environmental issues related to city's commitment to be an entirely carbon neutral city by 2025. The city of Copenhagen is a front-runner for smart cities initiatives deploying the digital technologies that address the challenges of urbanization and climate change by focusing on: Health, Mobility, Energy and Climate, Smart Citizens, Smart Learning. Smart Copenhagen project is based on three overarching themes that include: Data platform and privacy, Smart city infrastructure, Co-creation, and partnership. The distinguishing feature of Copenhagen smart framework is the wide access to data and efficient public-private sector partnerships delivering the world's first integrated city data exchange. The Copenhagen Connecting concept delivers a digital infrastructure across the entire city. The project assumes that the digital infrastructure is a basis for the future platform for smart city innovation assuming creation of digital twin in a similar way to physical infrastructure today.

Copenhagen adopts Open Data as a key component of the smart city strategy. The urban data is published online and accessible to anyone through city's open data portal: www.opendata.dk/city-of-copenhagen. The municipality publishes numerous data sets that include traffic simulation, maps of parking, air quality and more. Moreover, City of Copenhagen is implementing a City Data Exchange platform for combined private and public open data to create better public solutions. The Copenhagen City Lab develops solution for city stressors, including climate change and air quality. Copenhagen in collaboration with Google, University of

Utrecht, Danish Center for Environment and Gehl is creating a system for local air pollution monitoring testing new ways of monitoring and implementing smart sensors that can be easily moved within the city or attached to the vehicles.

Copenhagen

Strengths	Weaknesses
· ICT system as a main enabler for carbon neutral city economy (IBM Corporation 2013) · Global leader of city-wide data exchange (ibid) · Societal inclusion while decision-making (Ibid)	· Limited number of sensors for air quality and temperature. · Programs mostly focused on reduction of Co2, not directly addressing air pollution and temperatures (IBM Corporation 2013)
Opportunities	**Threats**
· City-wide deployment of sensors will improve other services · System can get more advanced including other aspects of smart city	Cyber-attacks Rising citizens' concerns on privacy and security due to pervasive deployment of ICT

Table 10. Copenhagen's' Connecting SWOT

Singapore City – Smart Nation Program

Fig. 29. Outline of the Smart Nation Program Singapore

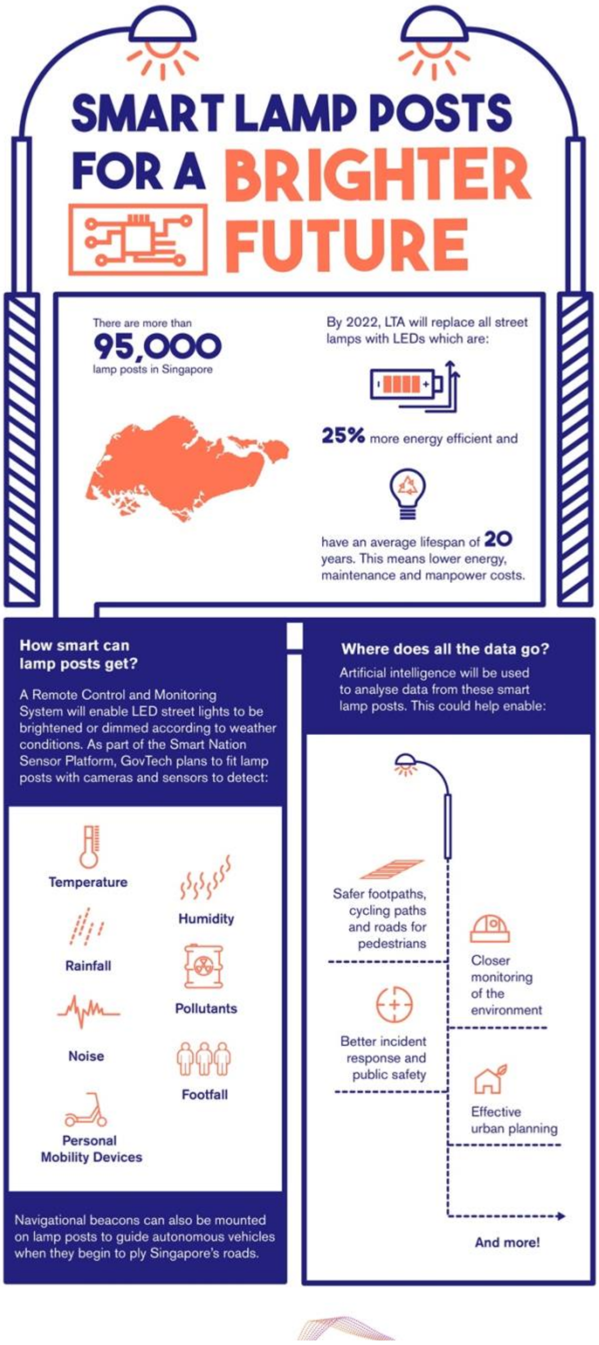


Fig. 30. Smart Lamppost project - outline

Singapore as a city-state island and relatively small area with no natural resources bases its economy mostly on information technologies. Since 1980s Singapore has been rethinking and implementing the ways ICT can improve enhance citizens life quality and country's economy. The most recent program (the Smart Nation Program) launched in 2014 introduces the ICT infrastructures to urban continuum assisting polices, urban ecosystem supporting the creation of a Smart Nation (SN). SN is a whole-nation program based on three pillars: Digital Government, Digital Economy, and Digital Society. The projects aim to touch upon goals such as National Digital Identity, E-payments, Smart Nation Sensor Platform (SNSP), Smart Urban Mobility, Moments of Life and CODEX (Khern 2019).

Considering this research, Singaporean SNSP project delivers fine insights to the technology deployment that collects city-level sensor data (available in 2022). The SNSP Smart Nation programme is built upon collection of urban data and data interpretation. The insights of gathered data will inform decision-making processes as well as will contribute to forming more automated solutions. The project will ensure that the Singaporean society will be able to read the data trends in real time data gathered will be displayed in real-time be able to display real time data cross country. Moreover, to facilitate better sense-making of the urban phenomena and increase situational awareness in a cost-effective manner the government will be able to collect and interpret the data. This will be implemented by a shared network of sensors developed as a part of SNSP by *Government Technology Agency (GovTech, n.d.)* so called Lamppost as a Platform (LaaP). The street lampposts will be facilitated with a network of wireless sensors and cameras that detect and monitor changes to environmental conditions like humidity, rainfall, temperature, and pollutants in the air.

Singapore

Strengths	Weaknesses
· Well-developed system (maturity)(Estevez, Lopes, and Janowski 2016) · Good use of pilot projects before implementing the service nationwide.(Keon et al. 2016) · Global leader of smart solutions (Keon et al. 2016)	· Maintain its competitiveness and economic growth.(Estevez, Lopes, and Janowski 2016) · Develop an e-Commerce hub (*ibid*) · Remain an international IT hub (*ibid*) · Avoid the technology polarization of citizens (*ibid*) · Concerns about personal data and peoples monitoring (*ibid*) · Reduce carbon emissions (*ibid*)
Opportunities	**Threats**
· A city-state, which means it is compact, efficient, and fast in the implementation of new solutions, pilots, and prototypes (Keon et al. 2016)	· Cyber-attacks (Estevez, Lopes, and Janowski 2016) · Drastic changes in the IT international marketplace can deeply affect the economy (Estevez, Lopes, and Janowski 2016) · Technology can divide the population (Estevez, Lopes, and Janowski 2016) · Be exclusively an IT knowledge-based development (Estevez, Lopes, and Janowski 2016) · Lack of monetary resources (100% funded by Singaporean government) (Keon et al. 2016)

Table 11. Singapore's SWOT

The analysed case studies present different approaches to the smart strategies that will enable environmental monitoring. The Table 12. summarises different aspects of implementing smart initiatives and sensor specification with assumed delivery date.

Key objective of introducing smart strategy	Smart initiative	City aspect	Number of sensors	Status
Citizen centric government	Sentilo	Energy, Noise, Garbage, Parking, Air Quality, Water Meter, Bicycle flow, People flow, Vehicle flow	19.822 (deployed) (interview*)	Available by the end of 2021
Societal equality	Array of Things	15 phenomena: traffic, air quality, temperature, vibration magnetic fields monitoring	150 (deployed) 500 (planned)(City of Chicago 2020)	2021 and beyond
2025 Carbon neutral goal, city-wide data exchange	Copenhagen connecting	Air quality and climate change parameters and more.	Sensing solutions converged on over 10 kilometres of road	2025 and beyond
Leader of smart solutions	Smart National Sensor Platform	City-level sensor data (temperature, humidity, air quality, noise, rainfall personal mobility devices, pedestrian monitoring)	110,000 lampposts (planned)	2022 and beyond

Table 12. Summary of the relevant initiatives per case study.
(interview) – interview with Jordi (Ajuntament de Barcelona)*

Rotterdam – case study

Rotterdam is the second the largest city in the Netherlands with the population 651.160 citizens and the area of 325.79 km^2. Its strategic significance led to noteworthy infrastructure damage during the second world war. Lack of historical landmarks enabled strong embracement of modern architecture principles city-wide. The main characteristic of this Dutch city is its marine port. Port of Rotterdam, the largest seaport in Europe, and excluding Asian ports, the largest port in the world. To optimize the operation back in 2009, port of Rotterdam started developing IoT-powered strategy to monitor the operation to determine the best time for ship docking (Appleton, 2020).

These innovations transformed one of the biggest ports in the world where time and efficiency is of prime importance to the industry, that bases its operation on data analysed by IBM's cloud based IoT technologies turning data into information to reduce wait times, determine optimal times for ships to dock, load and unload, and enable more ships into the available space (PortofRotterdam, 2021). This systemic upgrade was designed to improve the efficiency of business operations. While innovation in business most often occurs confidently and rapidly due to availability of financial resources, smaller scale of innovation implementation (compared with the civic transformation), limited number of other barriers (e.g., policies, interest parties etc.).

Bearing in mind socio-economic dilemmas, Rotterdam pursuits an ICT- enabled strategy that will mitigate current and future problems. Therefore, the city has defined an investment strategy, Roadmap Next Economy (RNE), to ensure that economic transition will occur in the region. RNE was published in November 2016 and outlines five transition paths: Smart Digital Delta, Smart Energy Delta, Circular Economy, Entrepreneurial Region and Next Society. While Rotterdam's smart strategies prioritize economic aspects, the environmental sustainability is barely included in the existing strategy.

Initiative	Key goal
Smart Digital Delta	better digital connections, networks, platforms and big data
Smart Energy Delta	Everything needed to set up an infrastructure for renewable energy: smart grids, new clean energy sources, CO2 storage, conversion, and storage technology.
Circular Economy	Anything that has to do with the use and reuse of resources and residues in the region.
Entrepreneurial Region	All the building blocks for a good, progressive business climate necessary to enable the transition to a new economy: new ones business models, products and services, new forms of cooperation, the development and support of start-ups, new legislation, and regulations.
Next Society	The actions needed to promote the inclusive society of the (near) future shape: developments in the labour market and education, cooperatives, citizen movements and new forms of communal (social) entrepreneurship and ownership.

Table 13. Outline of the smart strategies in Rotterdam

Moreover, Rotterdam participates in a cross-city project that is funded by the European Union. RUGGEDISED project – located in the Heart of South district, developing 13 smart solutions, that will help improve the energy exchange producing a neighbourhood where the sustainable energy (geothermal, thermal from waste etc.) is produced, shared, and used locally through a smart grid. Among 13 smart solutions, solution 10 include long-range wireless networks (LoRa) in Energy Management implementing Intelligent Street lighting, smart waste management and other applications.

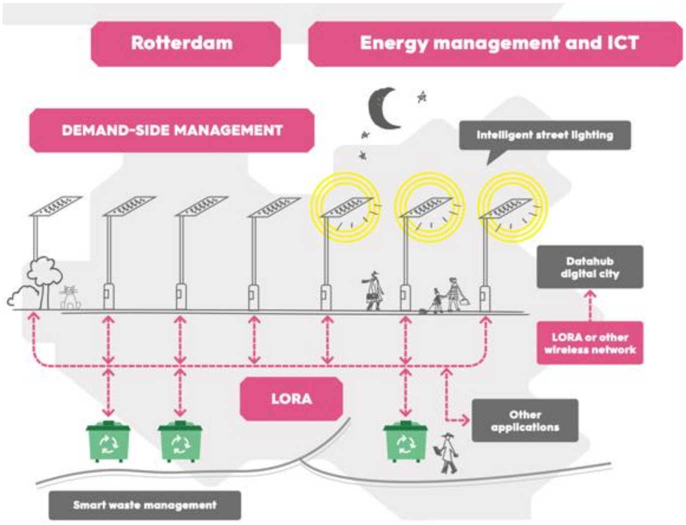


Fig. 26. Energy management and ICT program in Rotterdam (Source: Ruggedised)

Rotterdam has several urban labs for testing the smart solutions. The innovation district connects companies, start-ups and scale-ups for experimentation and production. As an example, the Climatelab Zomerhofkwartier lab, is particularly focused on climate resilience solutions to tackle the flooding and drought. Several other initiatives have been developed, including Smart Industry strategy, Smart City Planner, Smart Government, and similar projects. Sensible Sensors living lab in the south of Rotterdam is a project designed to see how can a sensos solution be developed for the benefit of the citizens looking at the design of the sensor and what residents want to know about sensors. The municipality also investigates what processes, resources and standards are needed to be able to work with sensors on a larger scale in the future.

Nevertheless, none of the previously introduced smart initiatives tackle air pollution or heat stress. Rotterdam implements some strategies for monitoring air pollution and temperature for example through the Lucht Club. The project is delivered by cooperation between the municipality and the citizens. The measurement data can be viewed live on an interactive map of the RIVM and is analysed in the collaboration with the DCMR (Rijnmond Environmental Service for clean, healthy, and safe living environment). The project uses input from 14 measuring stations and approximately 900 sensors that are being distributed among the participants giving more complete picture of the local air quality. As of today, on the interactive map which envisions current levels of air pollution (PM 2,5, PM10, No2, Temperature). There are approximately 20 sensors visible in Rotterdam, further 820 sensors will be visible in the future (please see the appendix Fig.4).

A remarkable example of cross-city cooperation is The Next Economy Roadmap where 23 local authorities are cooperating in the Rotterdam and the Hague metropolitan region (MRDH) to create environmentally-sound, self-reliant economies with a particular emphasis on community-driven projects. The roadmap mentions implementation of sustainable energy using renewables, energy conservation plans and many more. To meet the goals of The Next Economy Roadmap Rotterdam incorporates numerous smart initiatives, but again none of the smart initiatives are focused on measuring air quality and heat with IoT.

Rotterdam

Strengths	Weaknesses
· Mayor's strong vision (interview*) · Rapid boost of the initiatives (interview*) · Strong vision for economic development (interview*) · Strong cooperation of the region · (23 municipalities working on the project) (interview*) · Collaboration is recognized key enabler(interview*) · Private-Public Partnerships exist already (KPN)(RUGGEDISED 2020) · Smart City Recognition (interview*)	· Implement environmental sustainability into the framework as its not directly stated in the agenda (interview*) · Less international awareness, more local context (interview*) · Air pollution and heat stress are not included in smart city strategy (RUGGEDISED 2020) · Very limited air quality map provided by the Lucht program (luchtmeetnet.nl) · No interactive heat maps · Many smart solutions in place using different technology.
Opportunities	**Threats**
· Closer cooperation between the stakeholders for closer implementation · Further development of Smart City vision · People already recognize the importance of Smart city strategy (interview*) · Municipality recognizes the importance of monitoring of air pollution and heat stress (interview*)	· Increased competition with AMS instead of cooperation · Lack of secure funding · Different priorities for different cities (e.g., The Hague) cooperating on the same smart strategy

· Implementing the practice from the LuchtClub into Smart City strategy would be beneficial	

Table 14. SWOT of Rotterdam Smart Solutions
(interview) - interview with Rob, Rotterdam Municipality*

Conclusion & reference study takeaways

The analysis of four case studies that display a practice of implementing the IoT environmental monitoring gave important insights into the research outlining the strengths, weaknesses, opportunities, and threats of each strategy. Each city experience heat stress and air pollution problems to some extent and therefore is implementing a strategy that helps mitigate those issues. To enable the smart strategy, the cities share similar approaches to the smart strategy planning implementation and execution. All the case studies show that sensor data is key for better envisioning of urban stressors. In Singapore the implementation of ICT technology, contributes to improving the city cross disciplines. By implementing 3D city model, Singapore presents an immense opportunity for mapping different hotspots and improving city condition on different levels. Nonetheless, implementation of smart solutions takes time and is sometimes done by trial-and-error method. Experts mention that deployment of the concept of smart cities will take about a decade from now on. Barcelona, Copenhagen, Chicago put important stress on cross-sector and cross-city collaboration which gives possibilities of exchanging data, practice, and technology. When integrating many actors, a strong and clear vision and framework is fundamental. Importantly, Barcelona shows how significant is the public understanding, trust in in the government and how the government is handling the public and private data and therefore is actively inviting citizens to participate in smart city strategy.

Some barriers have also been observed in case studies and need to be considered when designing the strategy. Barcelona experiences problems with limited funding available and therefore the development of the smart strategy is slower and less vigorous. Many cities struggle to implement a uniform platform that display the data coming from diverse sensors located cross-city. Different shapes and kinds of data hinders analysing and envisioning of the data. The more actors participate in the deployment of smart city strategy, the more complicated it is to integrate different interest of different actors and therefore a strong vision of development of a smart strategy is key. On top of that, rising societal concerns on privacy and security of data due to pervasive development of ICT can be observed. Society recognises value in data and in some cases is not likely to voluntarily offer the personal data to the third party. Stronger European data security regulations is another potential barrier for IoT monitoring implementation limiting the availability of data.

Rotterdam, has been implementing smart solutions gradually, focusing mainly on the economic prosperity. Environmental aspect is addressed mainly with physical solutions (i.e., shading, greening, etc.). The sensing technology for heat and air quality monitoring is implemented by few programs (The Lucht Club – still under development). No IoT platform for displaying the data for environmental factors is in place. Rotterdam assumes strong regional and cooperation with other municipalities following strong mayoral vision involving the private sector in strategy development. Nonetheless, some weaknesses hold back the further development of IoT environmental monitoring (i.e., lack of the monitoring strategy, focus on economy, many projects scattered cross municipality with diverse technology).

Chapter 5: Strategy development

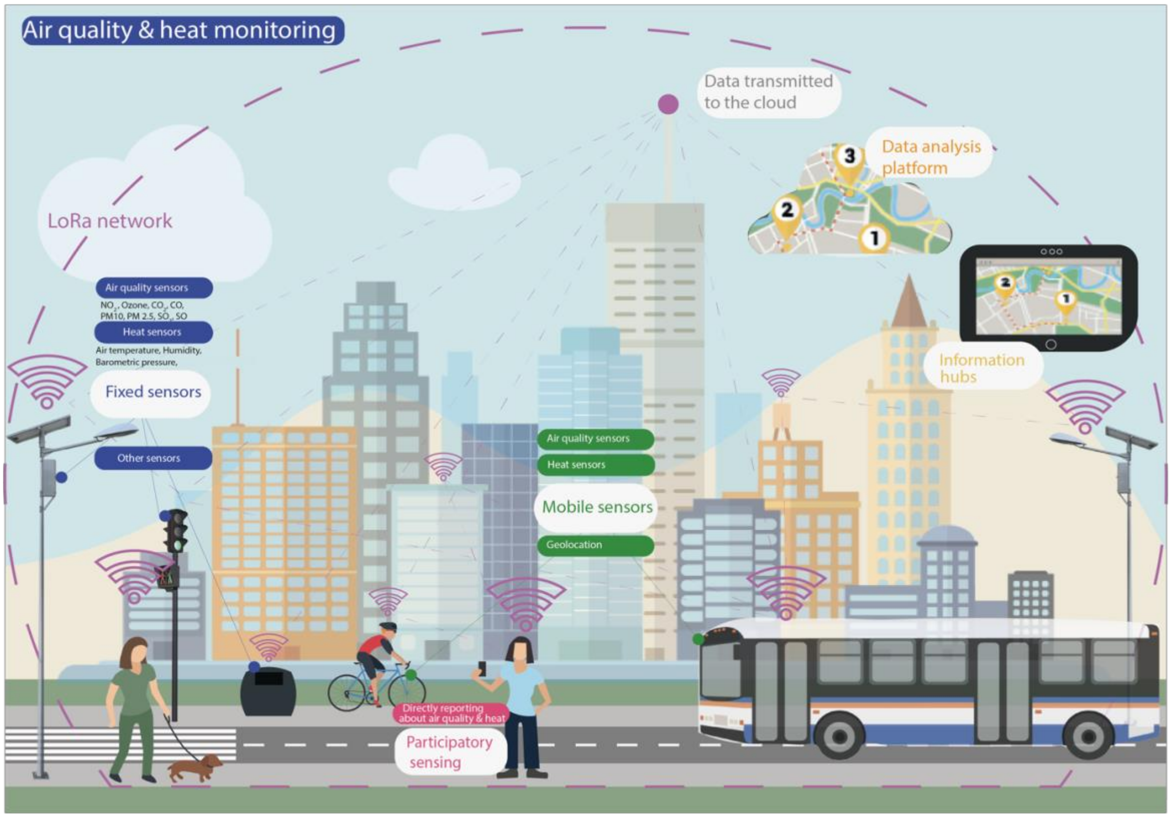


Fig. 27. Conceptual drawing of the IoT monitoring system for air quality and urban heat.

This chapter presents the findings of the research and translates it into recommendations for Rotterdam. The findings from the case study development chapter and the interviews with business and governmental representatives outlined 8 key focus points. The 8 key enablers are inter-related and to a certain extend one implies another. Within the spectrum of this master thesis and the IoT monitoring systems for heat and air quality the most adequate focus points are positioned on the technological and analysing side be that would <u>be technology and data analysis & display.</u>

Consequently, a major part of the strategy development and conclusion will analyse the technology and analysis and display. Further 6 enablers will be evaluated in recommendations.

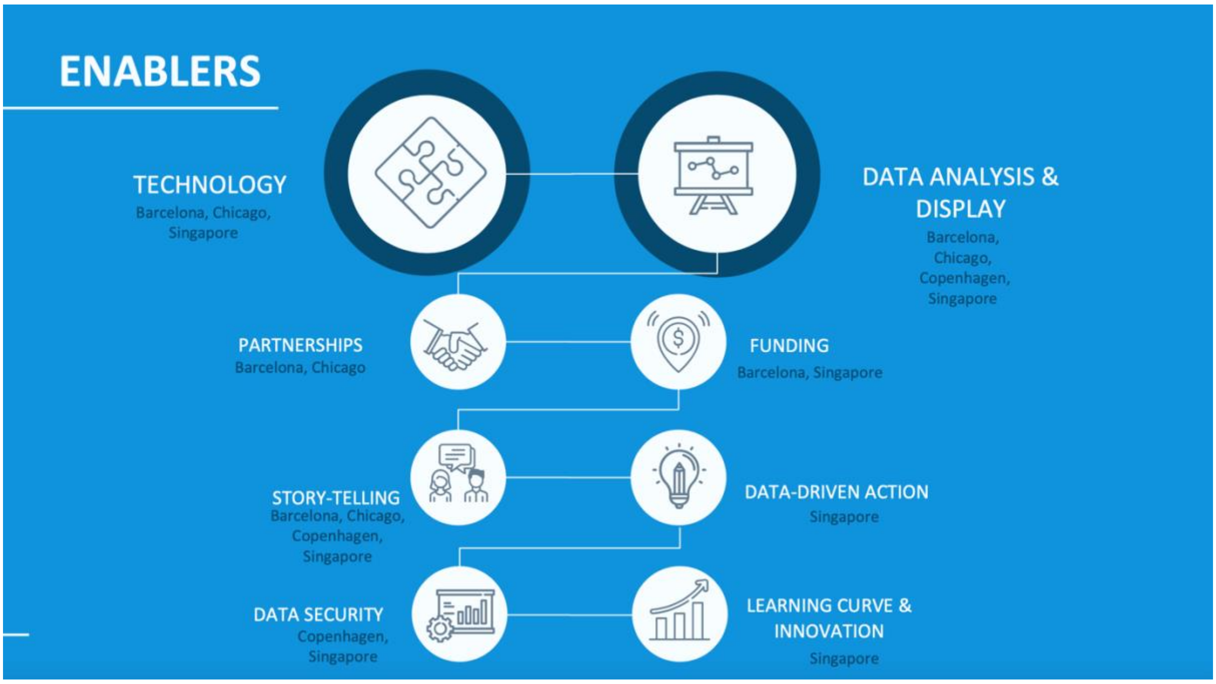


Fig 28. Proposed enablers of a smart strategy

When considering implementing smart city strategy it is important to acknowledge that no city is alike, and each city has its strengths, challenges, opportunities, and threats. Designing a framework that embraces clear strategy and vision is the most important success factor for a smart city and requires a clear strategy and vision to define city's ambition and the critical steps. Delivering a strong environmental, economic, and social vision allows to focus on the key steps to achieve the goals having a short and long-term strategy. After examining four case studies that are implementing solutions for better monitoring of urban environment, 8 strategy enablers were defined.

Enabler:	**Recommendation:**	**Source:**	**Expert:**
1. Partnerships	Cross-city/region new business models using data Cross- sector	Barcelona, Chicago	Dennis (KPN) Rob (Rotterdam Municipality) Jean-Pierre (KPN)
2. Funding	Must be available and not be limiting the development	Barcelona, Singapore	Jean-Pierre (KPN)
3. Data collecting technology	Integration between technologies and sensors	Chicago, Barcelona, Singapore	Feiko (KPN)

	Data plays key role of the future development, Ensuring correct data formats		
4. *Data analysis & display*	Open data sharing model, Standardization of solutioning, interactive platform Implementation of digital twin	Copenhagen, Chicago, Barcelona, Singapore	Feiko (KPN) Rob (Rotterdam Municipality) Jean-Pierre (KPN)
5. *Data security*	Trust and data security are founding factors for solution deployment	Copenhagen, Singapore	Feiko (KPN) Edwin (Huawei)
6. *Data-driven action*	Data-informed solutions for the city	Singapore	Edwin (Huawei)
7. *Storytelling and information*	Good and convincing narrative of the problem and clear message informing the society about the threats.	Barcelona, Chicago, Copenhagen, Singapore	Jean-Pierre (KPN) Edwin (Huawei) Monica (Medellin City Council)
8. *Learning-curve and innovation*	Learning through deployment of services	Singapore	Feiko (KPN) Edwin (Huawei)

Table 15. Enablers, cross-examined

The table above introduces the enablers paired with recommendations delivered from the reference studies and interviews with field experts. Although all mentioned enablers are crucial for successful delivery of smart city framework, an overall analysis is outside of the scope of this research. Therefore, additional information about the enablers together with additional suggestions can be found in further recommendations section. The following section talks extensively about Technology, Data analysis & Display enablers.

Technology, Data analysis & display enablers

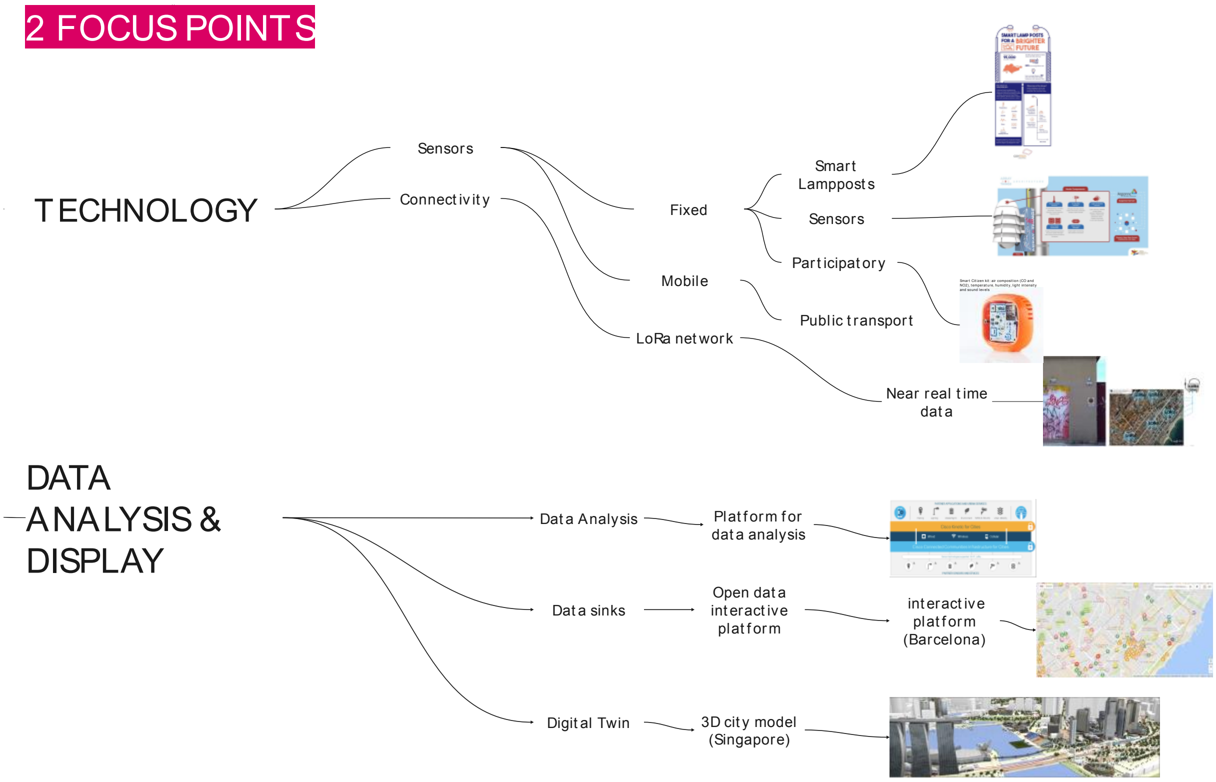


Fig. 29. Specification of two focus points: Technology and Data analysis and display.

Technology and data analysis and display section is divided into four sections. The first section defines the problems linked with the technology and data analysis and display delivered from the literature. The problem is linked with the suggestions delivered from the case studies. Technology section proposes the solutions for the physical side (hardware) for monitoring including different settings of sensors and connectivity settings (LoRa). Data analysis and display section mentions aspects of data analysis platform, data sinks and a digital twin concept. Last part of this section determines horizons for implementation for Rotterdam. The development horizons were delivered basing on data and technology stages outlined in "Smart Cities Report" delivered by Deloitte (Caragliu et al. 2015). Basing on literature and interviews, an assessment was made for Rotterdam defining its development stage.

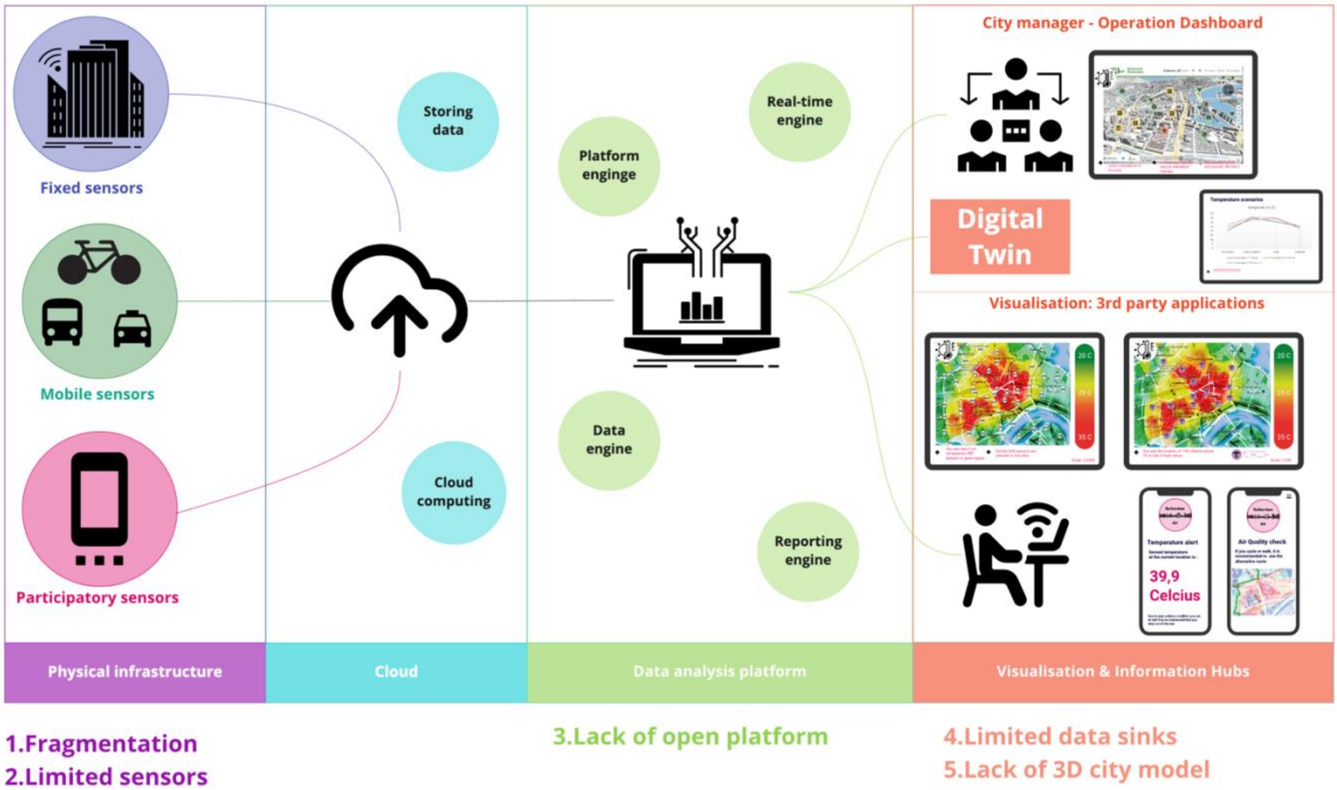


Fig. 30. shows a conceptual illustration of the proposed solution for Rotterdam that includes four stages: (1) Physical infrastructure, (2) Cloud, (3) Data analysis platform and (4) Visualisation & information hubs..

Stage 1 describes hardware technology that can be physically placed in different locations collecting data about the city condition from various points on the map. This stage is evaluated in the Technology subsection. Stage 2, 3 and 4 are discussed in Data Analysis and Display subsection. While stage 2 talks about accommodating data in the cloud and basic computing, Stage 3 includes more advanced data processing and interpretation within a platform. Stage 4 debates about possible display options for both city managers and third interest parties.

Nr.	Problem with data and technology	Key take-aways from reference studies	Case study	Rotterdam status	Recommended solution
1	Fragmentation: Diverse sensors, different data resolution	Scalable sensor technology that gathers data in a	Barcelona, Chicago	Air quality and heat sensors are not yet part of the smart strategy in Rotterdam, some pilot	Coherent technology that is scalable extensible and flexible for deployment and

	(spatial and temporal)	correct format citywide		projects have implemented energy measuring IoT technology	monitors air quality and temperatures
2	Limited number of sensors in cities	To achieve the greater coverage sensors can be implemented in lampposts, public transport, and participatory	Singapore	Sensor deployment is 840 air quality and heat sensors for the Lucht Club being implemented (20 visible). No further programs on heat and air quality monitoring	Design smart strategy for air quality and heat monitoring, implement numerous sensors depending on district characteristics.
3	Lack of open platform that analyse the data collected from the sensors, limited M2M communication, open data is not available or with limitations	Data is key now and, in the future, human mistakes can be eliminated by M2M communication, data needs to be easily retrievable in correct formats	Copenhagen	Data sheets on monitoring of urban heat, and air quality are not available or are not complete being difficult to retrieve the data sheets from	Alongside with sensor deployment a platform that analyses the data trends etc.
4	Limited data sinks where data trends can be displayed in a simple manner	Implement advanced and diverse data sinks so urban society can benefit from apps, platforms, public information on heat and air quality	Barcelona Copenhagen Chicago	Data sinks are limited. The Lucht Club displays certain information per location. Limited points of data. Other heat and air quality maps come from nation-wide models with limited spatial resolution.	Development of the interactive data sinks (i.e., App, internet platform, notifications for more vulnerable citizens, platform that displays data trends for the decision-making entities.
5	Lack of 3D city model hinders the modelling of the future scenarios	3D city model and collaborative data platform. for development of advanced tools and test-bedding concepts and services, planning and decision-making, and research on technologies to solve emerging and complex challenges for Singapore	Singapore	3D model of the city exists in a basic form and is still under development. No data on air quality or urban heat is displayed in the 3D map.	Alongside with sensors deployment, 3D model can be improved and facilitated with real-time data coming from the sensors creating a scenario for the cities in Digital Twin.

Table 16. Outline of 5 problems and solutions with technology

Technology – Hardware (1)

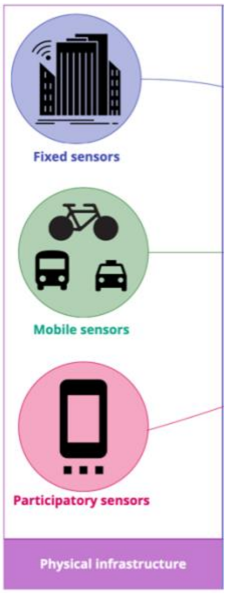


Fig. 31. Physical infrastructure of the proposed solution

Monitoring technology, data analysis and display are placed at the heart of smart city concept, especially in the context of air quality and heat monitoring. Implementing IoT monitoring solutions creates an unlimited opportunity for understanding of the phenomena. Nevertheless, certain limitations and barriers exist for implementation of such technologies. Currently, the most significant barrier for the technology is its fragmentation (Problem nr.1). Data, coming from different sources in various temporal and spatial resolution, creates an excessive barrier for interpretation of data in the data analysis platforms. Due to the number of existing solutions for IoT technology, different kinds of sensors, data analysing platforms and different cities approaches to different smart city initiatives a standard solution has not been yet designed. Introducing different technologies might affect in disjointed data retrieved with systematic gaps between technology. Consequently, it is essential that the sensors deployed in the city are compatible with each other in terms of data resolution and data coverage and potential extension of the system for further districts.

It is recommended that Rotterdam would set the standards for the monitoring system in the city. By setting standards, future technology and any further partnerships that will be required to obey the standards set at the beginning of the smart system development. In this manner the city of Rotterdam would be the key actor setting the IoT monitoring stage in the region and will avoid unnecessary transition costs. This will ensure data integration and its uniformity. The underlying enabler of this strategy is creating strong partnerships between the key actors involved in system. The partnerships define the financing of the initiatives and thus, sensor specification might vary per case depending on a service setting i.e., subscription, fixed architecture. After the agreements and financing has been established, the city should define the sensor technology. It is advised that the environmental sensors can be deployed flexibly in various locations ensuring future extension of the system. The collection of case studies outlines various methods of monitoring urban stressors: static (lampposts, city space), dynamic (public transportation) or participatory (engaging citizens) so the data coverage is more advanced (Problem nr. 2). Considering the diversity of the urban districts the scale and feasibility factors mixed solutions for monitoring are suggested. The city of Rotterdam would benefit from diversity of sensors that are structurally deployed in strategic civic locations, suggested by air pollution and temperature models to serve as an input for further consideration and in consultation with experts.

The example was delivered from the Chicago's Array of Things (AoT) case study. The system is an urban data monitoring scheme embracing programmable, modular "nodes" with sensors and computing capability which offers greater possibility for the internal data analysis (e.g., counting the number of vehicles at an intersection and deleting the image if no action is needed). The technology ensures real-time, location-based data delivery about urban environment, human activity etc. The nodes' locations were chosen with inputs from researchers, neighbourhood groups, city departments, and community members distinguishing locations in support of local concerns and interests (i.e., Air quality, urban temperatures, traffic) mostly on traffic signal light poles, on buildings (University of Chicago campus) or in other locations (cellular towers).

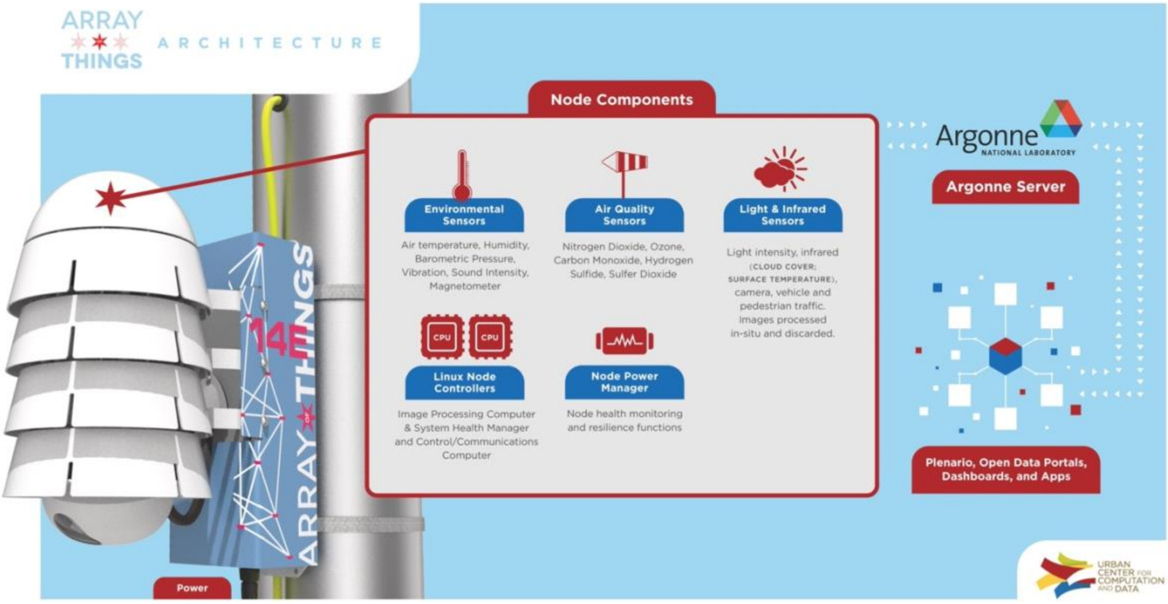


Fig. 32. Array of Things solution outline.

The example of AoT in Chicago displays a good practice for stationary sensors for environmental monitoring. The nodes can be allocated in the various locations flexibly cross city. The uniformity and various sensing possibilities makes AoT a powerful tool for data gathering. The nodes are facilitated in a uniform set of sensing capabilities. As of now, nodes can monitor temperature, barometric pressure, light, vibration, carbon monoxide, nitrogen dioxide, sulphur dioxide, ozone, ambient sound pressure, and pedestrian, vehicle traffic, solar light intensity (visible, UV, and IR) and cloud cover, and flooding and standing water. Moreover, the technology is focused specifically on monitoring urban environment and activity specifically minimizing any potential of collecting data about individuals in the city. Privacy matters take high importance in the AoT project building trust of the individuals in the project implemented by the municipality. Rotterdam is currently improving the citizens participation in various city projects for environmental monitoring by allocating sensors in private domains (i.e., private households). While implementing the sensor technology in the city for environmental monitoring, Rotterdam should pay additional attention for limiting the possibility of monitoring the individuals. The initiatives would then get higher societal acceptance and support. On the other hand, while choosing the sensing technologies the costs need to be taken in account. AoT singular node costs 2500$ as of 2019. The costs might hinder the wider implementation of such nodes. Chicago plans to implement 500 nodes over the course of project. Therefore, the total cost of nodes itself will equal 1 250 000$. Although advanced, Chicago's AoT is an expensive technology, and its price limits the numerous deployments of these sensors. The advanced nodes are capable of monitoring analysing significant amount of data but some locations in the city have different characteristics and some parameters not necessarily need to be monitored.

Contrary to AoT where one kind of nodes is placed in Chicago, Barcelona has implemented 90 various kinds of sensors that are positioned in various of locations. That would include lampposts, junction signs, urban bins, pavements, and other locations. Reduced number of sensors in a node reduces the size of the sensors that can be placed in diverse places. Compared with Chicago, the sensors placed in Barcelona are less complex, what follows less expensive and therefore more flexible in terms of numbers deployed. However, Sentilo project maps certain phenomena only at certain scales displaying the data as event hotspots.

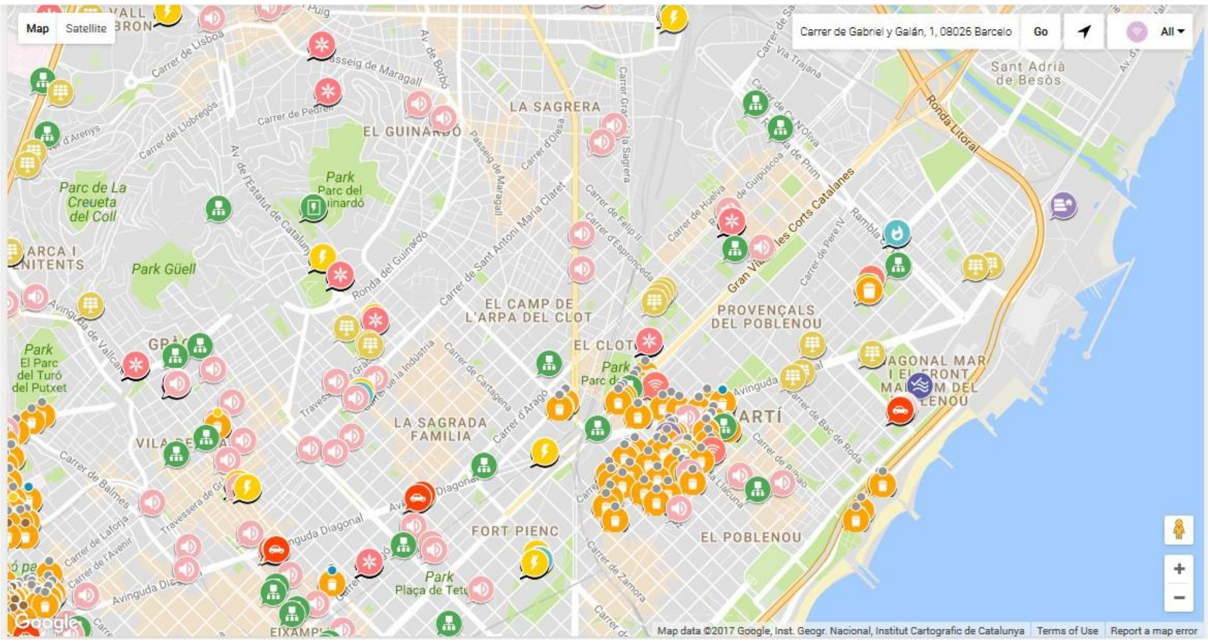


Fig. 33. Barcelona's network of sensors. Reported disturbances in real-time.

Smart lampposts technology is the example of the most advanced techniques for monitoring various aspects of the cities that is currently being developed. Different smart lampposts projects have various technology settings, architecture and serve different functions. The example of smart lampposts is displayed by Singapore and its smart lamppost project (LaaP). Each of the 95 000 lampposts that are planned to be implemented over the course on next years will be fitted with intelligent sensors (i.e., video, environmental and geolocation sensors) to deliver information about: Temperature, Humidity, Gas, Air Quality, Rain, and others. The LaaP project is connected via wired and wireless technologies (e.g., low-bandwidth, low-powered wide area network connectivity) using cloud-based infrastructure. Among others (i.e., Classification and Speed Detection, V2I – Vehicle to Infrastructure information flow, Crowd Analytics) it ensures localised environment monitoring enabling policymakers and actors to design better living around environmental factors, e.g., the flow of wind, the direction of sun's rays etc. Notwithstanding the LaaPs potential, some aspects of the smart lampposts have sparked concerns about privacy, and the cost of the project. The Singaporean government plans to implement facial recognition feature where wide range of citizen surveillance data can be collected and analysed allowing for facial matching against a database in real-time. This aspect of the project has been heavily criticized by Singaporean citizens (Aravindan & Geddie, 2018). Moreover, the estimated cost of implementing LaaP project at its minimal around SGD$ 7.500.000 which might not feasible solution for Rotterdam for air quality and temperature monitoring.

Alternatively, Rotterdam could implement location-customed sensor network. Depending on the location in the city area and basing on the environmental predictions, climate models and expert's opinion since different locations need different set of sensors. The custom-made solutions will allow the city to monitor certain trends in specific locations. For example: central locations of the city, where the effect of heat stress air pollution level is more significant could use more advanced sensors placed densely, equipped with the real-time or near real time temperature and air quality sensors. Depending on the density of the people living in given districts the number of sensors should also vary. The example network of sensors would include smart lampposts in the central locations which would be more advanced (compared with other proposed sensors) allowing additional features that can be added on the sensor platform flexibly. In less dense districts, part of the sensor network should be in the hotspots for air pollution and temperatures (e.g., road intersection, significant roads, industrial districts, spaces with the significant percentage of concrete). The location specific sensors would help lower the costs per node making the environmental monitoring more feasible.

To add on that, fixed sensors should be additionally supported by mobile sensors. This will help improve the mapping of the phenomena gathering data in real time in different locations. Public transportation systems (i.e., public buses, trams, rental bicycles) when facilitated with sensors will create a dense map of pollution and temperature in Rotterdam in each minute. Some cities i.e., Singapore are already implementing sensing technology into public transport. Most of the sensors aim to inform about live location and traffic condition and on top of that different sensors could be implemented (i.e., environmental sensing).

Participatory sensing would solely be on citizen's side. As a part of the monitoring citizens will be able to notify the municipality if in their opinion, certain places are too hot in summer season or the air in particulate locations is not of a good quality. This form of monitoring will deliver two functions: societal inclusion and local context knowledge. Through an app the society can report the events that will allow express people's needs with the regard to city space, filling the digital technology gaps with human observants.

Connectivity

Previously, most of the smart projects in Rotterdam (especially RUGGEDISED project) were aiming at using LoRa. Some projects (i.e., Lampposts – 185 streetlights connected with LoRa, 50 Parking spots were facilitated with sensors connected with LoRa) were basing on the LoRa network provided by KPN. Moreover, LoRa was the key connectivity network for majority of smart RUGGEDISED solutions. Nonetheless, for the projects in place other networks (LTE-M) were selected and therefore none of these projects currently run on the LoRa network (RUGGEDISED 2020). Even though currently there is a limited number of LoRa- based applications in Rotterdam, KPN and Rotterdam Municipality are still in the process of finding other opportunities to use LoRa. Better monitoring of heat and temperatures will require feasible connectivity platform. Since the technology is already in place, Rotterdam Municipality and KPN are encouraged to re-consider using LoRa network which is a feasible solution for IoT heat and temperature monitoring.

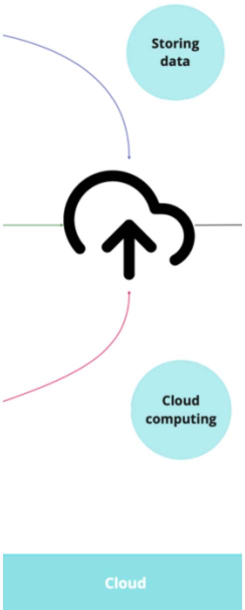
Data analysis & display

The second enabler that will be examined more closely is linked with the handling of information, including the methods for analysing and displaying the data. This section will discuss open data platforms that are in place represented by case studies. Moreover, this section will focus on data sinks and present the example visualization of how monitoring system should function. The third part will discuss further the development of the Digital Twin for Rotterdam.

Many innovative sensors can produce extremely large and continuous data streams. Various information (i.e., hyperspectral imagers, high-resolution cameras, 3D scanning devices) can produce big chunks of data each day. The amounts of daily data makes it impracticable for wireless sensor platforms to steam all data collected to the IoT platform for analysing (Beckman et al. 2017). To address the problems created by advanced monitoring, the remote sensor platforms need to decrease the amount of data inflow delivering only analysed results to a central server. To do so, edge computing performs computation bringing it and data storage closer to the devices where it is being gathered, rather than relying on a central location. Moreover, another problem associated with sensor data platforms are technological "silos" that make different cities too dependent on specific technologies, products or providers isolating the system from other technological solutions (Problem 3). Some suggest that to avoid technological silo structure, horizontal and cross-regional platforms with a cross-sectoral scope should be in place (Bain 2014). This indicates the important features of a wireless sensor platform include its extensibility, being open source and secure.

Waggle platform (Array of Things): Waggle means "*an elaborate dance that honeybees perform to communicate with the hive regarding the location of food sources*" (Catlett et al. 2020). Waggle is an open source wireless sensor platform created especially for Array of Things, Chicago project. It is capable of adaptation and extension enabling new sensors, computing and other IoT technologies to be integrated on the spot. Additionally, the platform is designed to support edge-computing to reduce the quantities of unanalysed data. The Waggle platform is designed to be open platform being able to support a wide range of sensors, to measure airborne pollutants such as hydrogen sulphide and ozone. Chicago is using the collected data to predict air quality incidents to take precautionary action but also to share the data with the public via the city's open data portal.

Sentilo Sensor data management platform



Sentilo wireless sensing platform is an open-source platform designed flexibly to fit in any city that explores introducing Smart City architecture focusing on openness and easy interoperability (Fig 35). Sentilo platform is open which facilitates integration of sensor data and actuators of any manufacturer without the need to purchase a conversion tech ology to read the data. On top of that, Sentilo provides an open API for various applications that are informed by data creating a simple and flexible framework to be extended to more use-cases. While Waggle uses edge-computing that is a way of computing at the location of a network – next to hardware and software at the physical locations cloud computing considers running the workloads of data within the cloud (RedHat,2021). The main difference is that for cloud computing all the data is sent to the cloud where it is computed. The edge-computing does not require cloud for computation.

Fig. 34. Second part of proposed solution

- Cloud

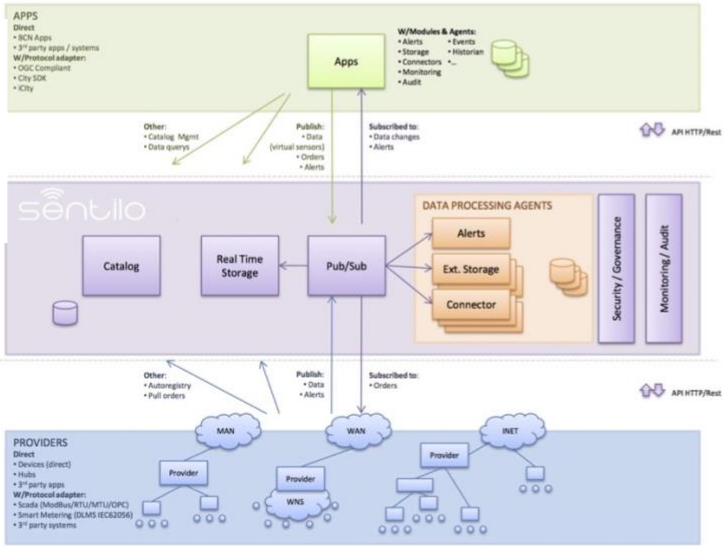


Fig. 35. Sentilo platform design. Source: (Bain 2014)

4 aspects of the platform

Fig. 37. Third part of the proposed solution; Data analysis platform

Developing a city-wide platform for Rotterdam might be the biggest challenge of all. The platform needs to be able to accommodate and analyse data coming from various sources (private and public), be flexibly extensible for any further applications build on top of the proposed system, send, and display the information near real time pacing and be easy to operate. To serve its purpose, four key components of platform have been predefined by Cisco (Cisco 2017) called 'engines' and implemented in the platform strategy.

1. Platform engine delivers Identity and Access Management (IAM) function which performs user authentication, authorization, user management and role-based access control. Moreover, IAM delivers information about location including locating and tracking devices on the map, providing geo-coordinates of specific facilities, roads, and city infrastructure assets. This function is crucial for understanding the positioning of sensors.

2. Real-time engine provides aggregation and abstraction of sensors from a diverse sensor cloud. Moreover, it performs normalization of data organising it and assigning attributes based on relations where raw data is removed and passed to the time-series data engine.

3. Data engine stores data feeds from the real-time engine analysing and providing time-shifted analytics on the stored data.

4. Reporting engine carries reports based on the real-time engine data providing input for applications.

Potential for developing a platform by KPN

Waggle and Sentilo platforms were developed by cities (cooperating with research institutes and private sectors) as the solutions for specific case studies (i.e., Barcelona and Chicago). Some of the platforms are being developed for almost a decade now. Both reference studies have given significant attention to the sensor platform development, designing, and constantly upgrading the technology. Some telecoms already offer uniform solutions for cities available for deployment in different locations. Cisco Kinetic for cities is a platform delivered by Cisco to collect data from sensors and devices throughout the city smart providing automated and secure data sharing across community infrastructures, solutions, applications, and connected devices enabling IoT data to drive new initiatives. The service is delivered on subscription basis therefore a city as a client, can decide when to start and to end the cooperation. Moreover, the platform is developed and ready to deploy.

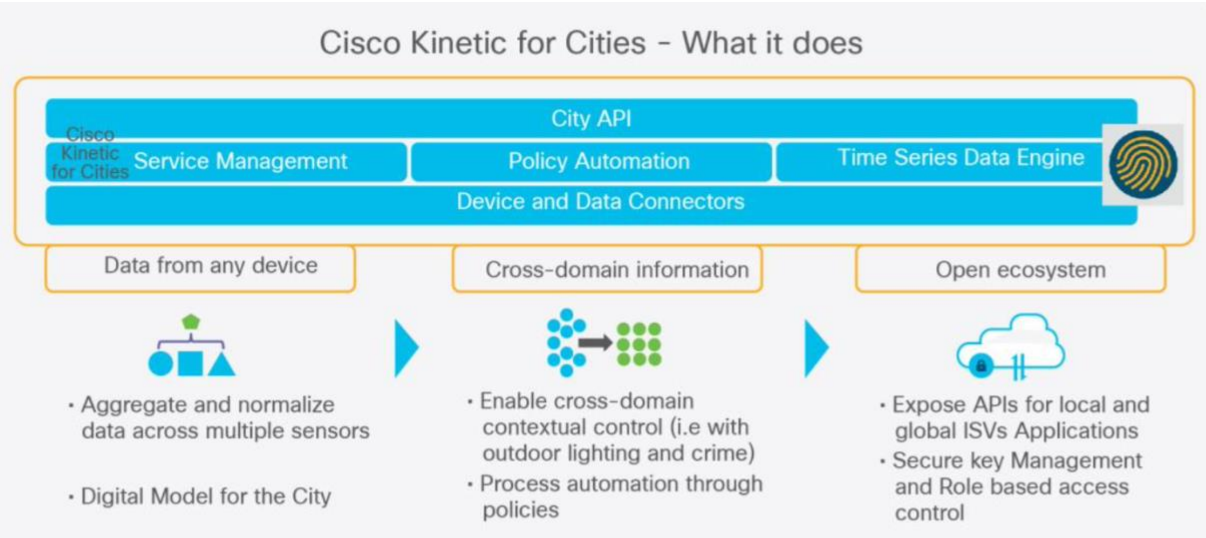


Fig. 38. Solution framework, Cisco Kinetic for cities (Cisco 2019)

KPN, the global front-runner for telecom sustainability solutions and leading telecom in the Netherlands has therefore a rising opportunity to develop a platform that will help monitor the air pollution and temperature trends in the cities. Although an IoT monitoring platform is not yet in place, KPN has been developing numerous solutions for commercial IoT services (i.e., Data Service Hub, Things KPN) and therefore can extend the IoT platform designing a solution for cities.

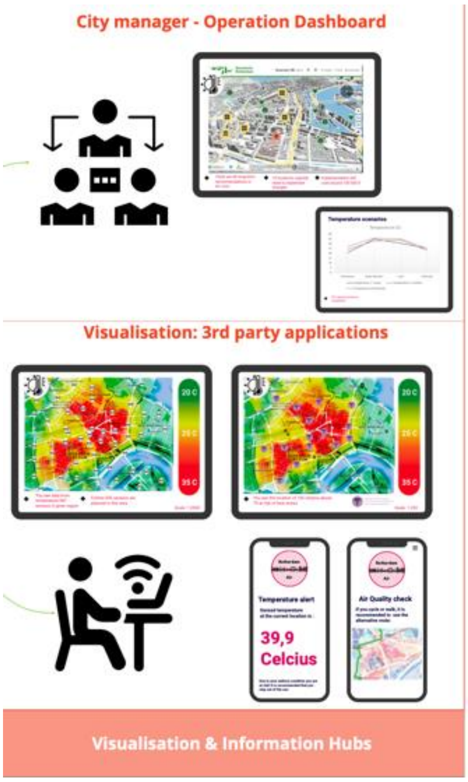


Fig. 39. Proposed strategy - Visualization and information hub

Data sinks

Currently, Rotterdam has limited data display. Its new open data platform (rotterdam.dataplatform.nl) has eight datasheets that display factors like greenery, city quatres, street index etc. The data can be downloaded from the website. Nonetheless, no visual display of the data is provided. This section touches upon the aspect of limited data sinks (Problem 4) where city's data is not displayed in an easy-to-read manner and therefore not considered. Barcelona has introduced a monitoring tool providing data envisioning instrument that allows the reader to see and understand different aspects of the city envisioned on an interactive map. The interactive maps allow the full informational potential for data that can be better understood by the target groups. The solution derived below (Fig. 40.) presents an exemplary data display feature in a form of a mobile app for both, city managers and for the citizens.

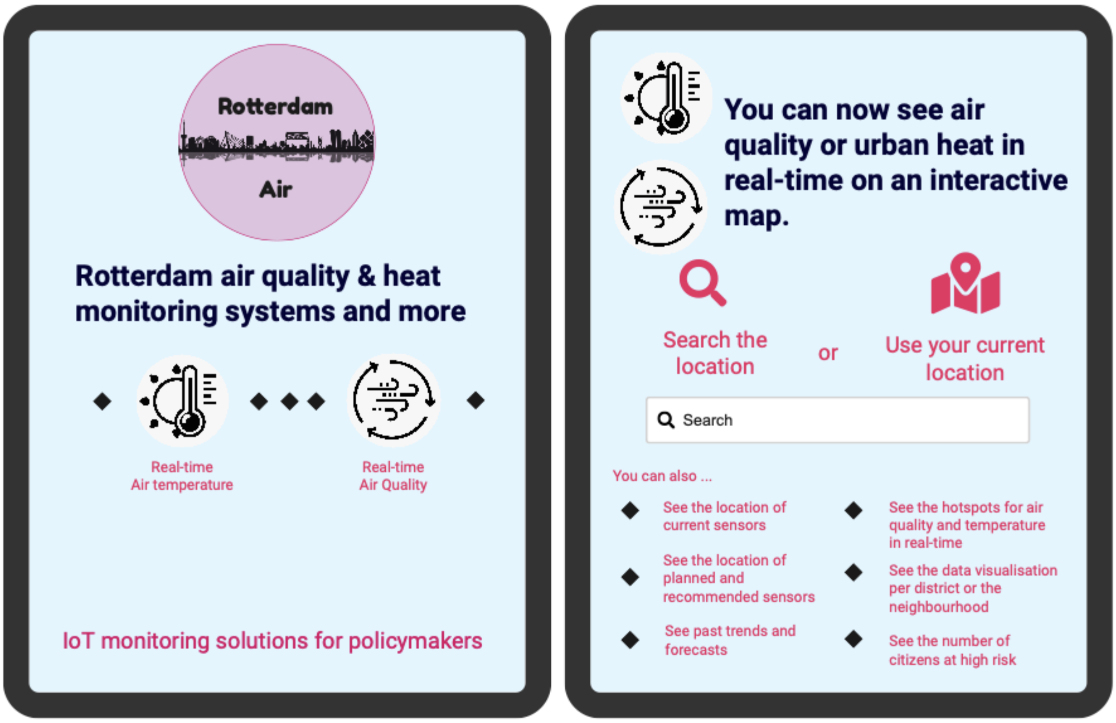


Fig. 40 Rotterdam Air app for city managers.

The proposed visual solution covers a variety of topics. Through this system, policymakers can see the air quality and temperature in real-time and in chosen location. The number and the exact location of operating and planned sensors is displayed. Moreover, the data collected in different locations can be translated into a short-time temperature and air quality forecast. The service then can be inter-connected with different city services i.e., smart mobility platforms that inform about the current traffic condition and therefore predicts the air pollution levels. The smart health services can give information input about registered citizens with health condition (i.e., cardiovascular diseases, asthma, elderly etc.). The app then can send the notifications (Fig.41.) to the citizens at risk. Moreover, citizens will be able to check the optimal route when cycling or walking to avoid the extensive air pollution.

Fig. 41. Proposed solution for 3rd party alerts.

Further, when the Rotterdam's Digital Twin is fully developed and the sensors are delivering data packages, the app can display the recommendations and potential solutions for improving air quality and heat stress points in the city per location.

Fig. 42. Proposed link between app and digital twin where the suggestions can be automatically delivered.

Digital Twin City

The complications generated with rising urbanisation, force the governments to incorporate solutions that will be able to display, analyse and manage those problems. The concept of the Digital Twin City (DTC) has been put forward as a crucial point of the digital transformation for many cities (i.e., Singapore, Atlanta, Rotterdam, Shanghai). DTC ensures that any physical structure, process, or flow withing defined boundaries has its digital representation creating a mutual symbiosis between digital and physical entities (Deng, Zhang, and Shen 2021). A Digital Twin consists of three segments: physical structures, virtual structures, and the connection between them integrating hardware, software and IoT technology for better envisioning of the urban phenomena. Although, DTC seems to be an impeccable solution for improving the condition of the city, its complexity, financial matters, and numerous elements like sensors that need to be deployed hinders the deployment in many places.

One of the most pivotal examples of a DTC is Virtual Singapore Project – a digital representation of the country, that has been launched in 2014 at a cost of $73 million. The Virtual Singapore is incorporating and displaying semantic information of different features of the city in real-time presenting a 3D digital world. The aim of the project is to bridge the gap between physical and digital worlds assuming integration of large volumes of data that combines sensor data and external data sources (i.e., geospatial information and building information). The project is predicted to significantly contribute to more efficient urban planning for instance providing insights into how ambient temperature and light intensity vary throughout the day in different locations delivering semi-automated planning process. Virtual Singapore can investigate improved urban accessibility or analyse the potential for solar energy production. The project sources data from governmental agencies, existing models, pre-defined information, and the real-time data provided by the network of sensors and IoT devices (NRF, n.d.,).

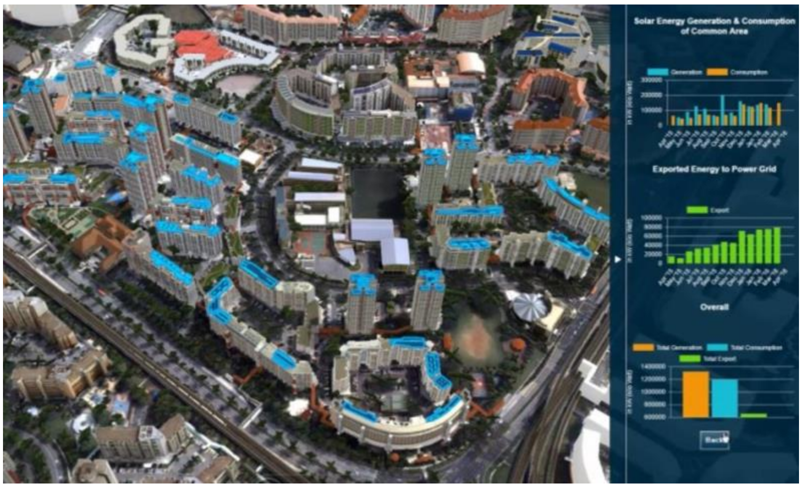


Fig. 43. Virtual Singapore: solar energy potential

Although, still under development, upon its finishing, the Virtual Singapore

Virtual Singapore will allow the public, private, people and research sectors to use and develop hi-tech tools and applications for test-bedding of different services and decision-making to solve the existing urban problems in Singapore. Virtual Singapore displays four major capabilities: Virtual Experimentation, Virtual Test-Bedding, Planning and Decision-Making, Research and Development. The virtual experimentation and test-bedding tools allows country-wide virtual test-bedding and experimentation of various technologies and concepts to validate the provision of the services. Planning and development platform integrates various data and allows developing analytical applications for facilitating urban living. For instance, a transportation app that analyses transport and people flows. Research and Development application will provide the research community the necessary and accurate information to innovate and develop new technologies. The example of Virtual Singapore displays promising outcomes of incorporating a digital twin version of the city. Incorporating the projects in virtual reality can reduce the costs of the transition and ensure justified solutions for the cities.

Rotterdam has potential for advancing its 3D model, mapping the sensors that can deliver more accurate data on condition of current air pollution and heat providing an advance spatial analysis of multiple local arears in the city of Rotterdam enabling solutions for Test-bedding & Virtual Experimentation, Planning and Decision-Making, Research and Development. Nonetheless, development of a digital twin might be the last step of IoT strategy development since it is a highly complex process. To be fully deployed, digital twin requires sensor technology that provides real-time data inputs.

Chapter 6: Validation & Conclusion

The objective of the research was to develop a conceptual framework that is based on relevant theoretical constructs and practical expertise from various actors involved in the smart city topic. Since the model of IoT monitoring solutions is expected to be used in practical settings, the external experts from public and private sector were invited for an evaluation conversation that provides inputs for measurement of success of the framework and correction of defects.

List of experts:

1. Rob Schmidt - Project manager Smart City & Digital Economy at Gemeente Rotterdam
2. Eduard Schoor - Advisor Urban Water and Geohydrology at Gemeente Rotterdam with expertise in urban heat.
3. Patricia Timmerman - Advisor Air quality and soil at Gemeente Rotterdam
4. Feiko Gorter - Lead IoT expert at Cegeka

The evaluation conversation is divided into three sections. Firstly, the visioning section asks the experts to envision a 'perfect solution' for monitoring and mitigation of air pollution and heat stress in Rotterdam. This section aims to deliver the insights of what private and the public sector are expecting from a delivered solution, indicate different priorities for actors discussing what is possible and in what time frame. The solution is not restricted by financial matters which will allow accurately distinguish what is desired in the field of IoT monitoring. Second part presents findings of this research, explaining the proposed framework. This section brings the participants closer to the solution assessing its technological and organisational matters. The third step is the general assessment of working solution through SWOT analysis. The experts comment on visible weaknesses and strengths of the solution assessing its feasibility and outlining the biggest problems of the solution. The evaluation conversation is 60 minutes long and the outcomes of the meeting are as follow:

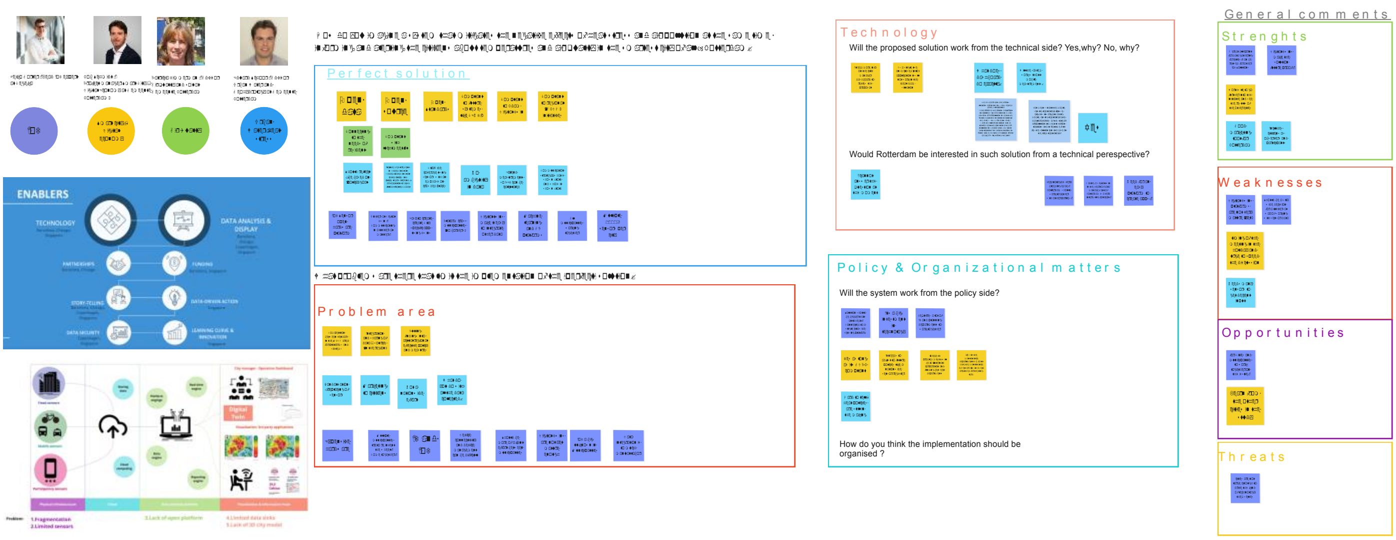


Fig. 44. Outcome of the evaluation conversation.

In the visioning, the participants were asked to answer the question: "*How do you imagine a system that mitigates the negative effects of heat stress and air pollution at the same time informing and alerting the citizens about temperatures and air quality in the smartest city of all – Rotterdam?"*

Each expert could therefore envision the perfect solution for monitoring system in Rotterdam. Referring to the outcome, the 'perfect solution' would be: open source, open data, open standards, compliant with future system and the existing 3D model of Rotterdam, compliant with existing incentives and the regional standards. The solution should also reflect the needs of the residents, be simple and encompass numerous sensors for better data envisioning, basing on the regional cooperation between partnering cities and interest groups. What follows, the experts were asked to outline the main problems that might occur looking at the perfect solution. This includes competition between the vendors, problem of information and data sharing, creating data-driven policy at the regional level, marketing problem, feasibility of the solution, lack of cooperation between the municipalities, device connectivity and managemnet is a difficult task, technology is not yet mature enough etc.

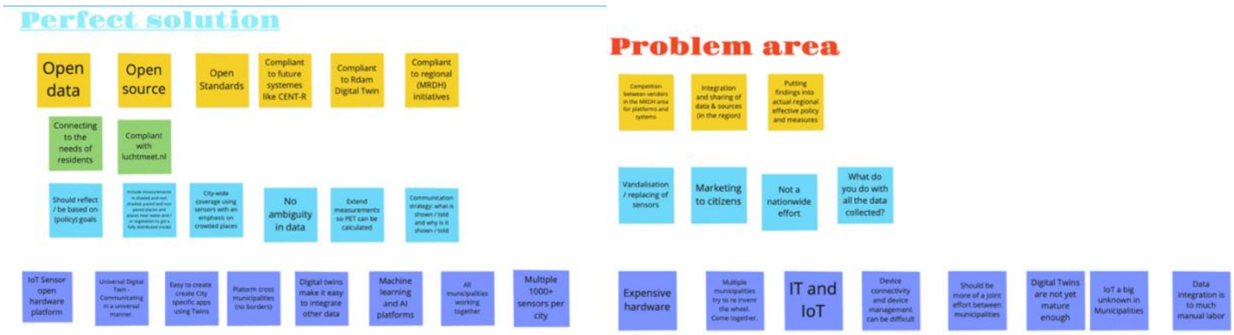


Fig. 35 & 36. 'Perfect solution' vs. main problems outlined.

In the second part of the conversation, the participants were asked to assess the solution proposed in this thesis in a context of technology and policy. The outcome of the technology suggested further development of the solution, especially the proposed manager dashboard and implementation of multifunctional system for monitoring wider number of factors linking the proposed strategy with other smart city initiatives. Furthermore, it was suggested that while approaching the initiative, Rotterdam should enter closer collaboration with neighbouring municipalities. Looking at the policy, the proposed solution should be: General Data Protection Regulation compliant and account for future policies (e.g., nationwide sensor registers). Importantly, the internal organization of the solution between the departments needs to be appropriately defined and funding allocated to enable smooth and long-term coordination of the solution. Additionally, the solution might be the subject of further adjustments since some policies (i.e., heat policies) are still in a process of making.

The third part of the conversation was the general assessment of the solution in a form of SWOT analysis. The strengths of the solution were outlined as: futureproof solution thanks to implementation of Digital Twin, a great blueprint for data gathering for cities that can be used in different IoT solutions, good marketing tool for Rotterdam that accounts for citizens as the observers and participants. The weaknesses of the solution were outlined as: needs many sensors to get decent input, the technology (i.e., Digital Twin) is not yet mature, the solution should be a city-wide decision for a universal way of working with the sensors. Among the opportunities, the further learning from other cities closer collaboration between cities and municipalities on a uniform IoT solution is mentioned. Threats section mentions that cities are not large enough to drive this kind of solution by themselves and therefore need to partner with other interest groups (i.e., other cities or actors).

Conclusion

Growing urban population paired with changing patterns of global climate poses a great challenge for the cities. Within less than three decades it is predicted that 6,7 billion people will be living in urban areas, that will require additional infrastructure for mitigating the pollution. Climate change is predicted to cause more severe weather events, floods but also heatwaves and droughts. Dutch environmental agency (PBL) expects climate change to cause change in the weather patterns including hotter and drier summers and outlining urban heat stress as threat for large number of the society (>100 000 people affected and causing >10 deaths). Moreover, heatwaves bring the increased usage of electricity for cooling (i.e., A/C), additionally contributing to rising urban temperatures. The increased electricity intake is linked with the enlarged CO_2 emissions, and consequently, a positive feedback loop can be observed. Air pollution in urban areas significantly reduces the life expectancy of the population. In the urban areas, main sources of air pollution are transport and industry. Pollution concentration highly depend on the location and source of the pollution. Closer monitoring, that will lead to more informed decision-making of those two environmental factors is urgently needed globally, especially in global south where pollution standards are not defined or not followed.

The examined case studies displayed different approaches to IoT monitoring exhibiting key enablers and barriers for implementing strategy. Better monitoring of air quality and temperatures in the city of Rotterdam will support the policymakers in developing solutions for air pollution and heat. Rotterdam recognises the need for mitigating the heat and air pollution problems. While heat is tackled mainly with physical solutions such as green roofs, green façades and sun protection mechanisms, air pollution is monitored by ground stations and models and remote sensing (RotterdamsWeerWoord.nl, n.d.,). Nonetheless, majority of air pollution mitigating strategies in place is not specific enough, and cannot display the pollution trends on a local scale. The need for closer ground monitoring of both factors is evident and the city is actively looking into developing innovative and advanced solutions. However, as of now, smart city strategy for Rotterdam does not include the IoT monitoring system that monitors environmental factors like air quality and heat. There are projects that are deemed to be ground-breaking as The Lucht Club, however they are not yet fully implemented and will provide set of sensors with limited IoT capabilities. The greatest challenge for implementation of IoT solutions in Rotterdam is currently the fragmentation of solutions. Currently about 200 smart solutions are placed or planned in the city. Most of the solutions is using different technology delivered by different providers.

The proposed monitoring solution for Rotterdam tackles the problem of different technology suggesting the collection of compatible sensors in three modes of sensing data: fixed, mobile, and participatory. The combination of different modes of compatible sensors will provide higher coverage of the area collecting similar data packages that can be communicated to IoT platform. Planning of the sensor location plays important role and should be specified beforehand through consultation with experts and basing on the existing data. The knowledge base should be defined including the scale of the problem (i.e., basing on previous reports how significant the problem is expected to be in given area) outlining the potential impact on the society, economy, and environment, in a short and a long-term prediction (including climate change variability and societal patterns). The city map should be assessed prior starting the project assessing the locations of existing data monitors and potential sensor locations to recognise areas of Rotterdam with air pollution and heat stress information gaps. The locations of the sensors should be chosen basing on their surrounding in terms of surface building materials, site geometry, and human activity. Additionally, a reasonable network of sensors in different locations needs to be established. A consistent protocol for the location needs to be specified in terms of the height and direction of sensors, the shadow and other factors that influence temperatures and air pollution level. The data reporting needs to be clearly documented with appropriate methodology and metadata (i.e., time, area, variables etc.,).

Secondly, cloud computing will provide first stage of computation and data selection solving the problem of high amounts of unarranged data that might not be significant for policymakers. Thirdly, the platform will analyse and translate the received data into a reporting component basing on a real-time, and time shifted data analytics basing on past records and external data. The platform must be capable of analysing data coming from different sources including private parties and different sensing technology. Lastly, the visualisation tool will help policymakers envision, analyse and display suggestions on how to improve the existing system. The proposed system will be capable of sending warnings about the current levels of pollutants and temperature per specific location. Furthermore, basing on the map, system will be able to indicate a route through the city with the lowest levels of pollution in real time – this function can be compared with google maps and its traffic congestion display and prediction. Additionally, the improved Rotterdam's 3D model can serve as a Digital Twin that basing on sensor data output but and external data can serve as an experimentation ground for actors interested in air pollution and heat. On top of that a Digital Twin can display localised suggestions for improvement of physical and digital infrastructure. For example, having the information about the building material and components and the greenery, the Digital Twin will be able to display the areas and suggest possible improvements. While Digital Twin appears to be a feasible such solution it will require number of experts working with the model, providing the insights to the system at first manually to give the initial guidelines to Artificial Intelligence (AI).

The solutions for improved monitoring will contribute to better understanding of urban problems and therefore improve the health of the urban society and provide more sustainable solutions. More knowledgeable society can make more informed decisions regarding choosing commuting routes and be warned if the surrounding air quality is not sufficient or if the heat is too extensive. This might reduce the number of deaths due to environmental factors. Nonetheless, further research in this matter is recommended. Looking at the sustainability, the improvement levels will depend on the action taken by policymakers. Better monitoring will inform the policymakers about the source and the location of the problem. While connecting the proposed system with other IoT services, the city can more efficiently prevent the pollution re-directing the traffic or changing the operation patterns of polluting sites as powerplants, or industry. Climate change poses a great challenge for current and future urban societies. Together with sea-level rise, temperatures rise, and thus urban heat stress will become a significant issue. Tackling it will become a pivotal aspect of city management. Better management of the urban temperatures will improve citizens wellbeing and will reduce the energy needed (ex., A/C) for cooling down the city area which can contribute to higher sustainability levels.

Horizons of implementation in Rotterdam

The final section of the conclusion includes the horizons of implementation of the smart strategy in terms of Technology and Data analysis. Four stages have been defined by *Caragliu et al. 2015 in the Smart City report.* The report defines smart city development staged basing of the advancement of the strategy in place. Considering the topic of this thesis, two factors were outsourced, namely Technology and Data Analysis. The table 17 & 17' compares development stages defined by Caragliu with the current development of Rotterdam. This report suggests that Rotterdam can be now placed in the Intentional stage of development which was validated by experts from Rotterdam municipality [Appendix.1 interview 11].

To achieve before mentioned solutions, four development stages have been defined for technology, data analysis and display. In the **Initial stage** some basic developments have been implemented to support IoT. Nonetheless, numerous problems with data formats and technology still exist. **Intentional stage** presents a set of actors involved in the deployment of small IoT projects in the city. Moreover, the existence of dedicated IoT platforms and networks can be observed. On top of that first standards and policies for IoT monitoring have been drafted at this stage. After analysing Rotterdam's strategy and its smart projects, Rotterdam can be placed in the intentional stage. The **Integral stage** describes city-wide examples of IoT solutions paired with smart city standards and policies. **Transformed stage** describes a fully deployed IoT technology in the city that is continuously developing and improving. The data coming from cross-organization architectures creates a complete visual overlay of the city. To reach the transformed stage, Rotterdam still needs to strengthen its smart vision, invest in sensing technology, and further develop the city digital twin and IoT connecting various architectures cross sectors so it can envision different urban phenomena in real time within one application.

Enabler/ Stage	**Stage 1: Initial**	**Stage 2: Intentional - Rotterdam Stage**
Rotterdam (Technology)	Fixed and mobile broadband internet in place LoRa city-wide coverage provided by KPN Some investment in sensors and IoT technology - but mostly for other projects not related with monitoring of HS and AQ	Energy exchange project in with shared architecture Different stakeholders involved (KPN, research institutes, citizens, private actors)
Development stage guidance: Technology	Fixed and mobile internet broadband networks are in place. Technology architecture is characterized by point solutions for line of business applications. Limited investments in sensors and M2M networks.	Shared architectures are deployed on a limited set of services. Stakeholders are intentionally investing in sensoring technologies. Dedicated M2M / IoT networks (low bandwidth, high range) are in place.
Rotterdam (Data analysis) (Caragliu et al. 2015)	Data is collected beyond the context of a traditional city. Data is analysed and to some extend opened to public and to some extend in real-time	Small IoT pilot projects in place Data is being reused for pilot IoT projects 3D model exists in its proof-of-concept stage but is not real-time data implemented

Development stage guidance: Data analysis (Caragliu et al. 2015)	Data is collected in the context of traditional city processes / responsibilities only. Data is used for the delivery of a particular service and not re-used for other purposes. Basic analysis of data in the form or simple reporting on isolated data sets. Data is stored in disparate systems and is difficult to access and combine. Some data sets are opened to the public, but only historic data (no real-time data). Data quality of open data is not guaranteed, no mature data management processes. Policies for data sharing, privacy, anonymization, authorization, charging & monetization etc. are not in place.	Small scale pilots to collect (IoT) data specific for smart solutions are in place. Small scale re-use of data to fuel smart solutions and data analytics. Pilots with advanced data analytics on city data emerge. Technical solutions (data platform) to combine and re-use data emerge. Pilots with providing real-time (IoT) data are being set up. Initiatives to define data management standards and processes are in place Partners (city and external parties) have identified the need for such policies and initiatives are in place to define them.

17&17' Horizons of implementation in Rotterdam define the necessary steps for Rotterdam to achieve maturity of the IoT monitoring solutions.

Enabler/ Stage	***Stage 3: Integral***	**Stage 4: Transformed**
Rotterdam (Technology)	IoT platform is not available Only certain sensors visible depending on the project (27 from Lucht club) Other smart projects are in place and Certain data standards in place but not specifically addressing urban heat	Some elementary technology architecture is in place. Smart city projects are at the stage of implementation therefore continuous learning is not yet in place Only limited number of pilot projects in few places,
Development stage guidance: Technology	City wide implementation of an IoT platform unifying management of all kinds of sensors. Joint investments plans for city wide deployment of connected assets with multi purpose sensors. Standards and policies are in place to create integral architectures.	Cross organizational technology architectures are in place. Continuous learning and improvement of the joint architecture to support innovation and transformation. City wide deployment of connectivity infrastructure and sensors networks for all major smart solutions.
Rotterdam (Data analysis) (Caragliu et al. 2015)	No city-wide collection of IoT data Multiple sources are being implemented, data is not yet combined No city-wide real time IoT	Solutions implemented in Rotterdam are not yet at this stage.

Development stage guidance: Data analysis (Caragliu et al. 2015)	First city wide collection of (IoT) data specific smart solutions is operational Data is combined from multiple sources in ne creative ways. Data analytics is applied on combined data s to provide new insights Government services and external partners u the data platform for their open data First city wide examples of real-time (IoT) dat are operational Data management standards and processes are being implemented. Partners have agreed a first version of data policies and start using them in practice.	Data fueling the full spectrum of smart soluti is collected. Data from various sources is used to create complete visual overlay of the city. City wide use of mature advanced data analytics (real-time, big data, predictive). All data is available through a single "data hu and via open standards. Open data encompasses full real-time (IoT) data to be used by smart solutions. Operational data management standards an processes, data quality is guaranteed. Data by parties in the ecosystem use is governed by agreed data policies.

Further Recommendation

Further recommendations section evaluates six enablers outlined in *Chapter 5: Strategy* - Partnerships, Funding, Data security, Data-driven action, Storytelling and Information, Learning-curve and Innovation which are equally important and need to be further investigated.

1. Partnerships

While the concept of smart city is still evolving and it is predicted that IoT and data driven solutions will play significant role in daily life within a decade, large number of companies involved in the IoT ecosystem and what follows the diversity of solutions might lead to fragmentation especially in absence of external interventions. The fragmentation might cause negative externalities that would include higher costs of technology, due to lack of economies of scale, lack of industry-wide standards which might influence interoperability and the extension capabilities. Lack of strong partnerships might also influence speed of deployment having the impression that the technology is still evolving.

Establishing partnerships between key actors engaged in building a smart city strategy is crucial, and the governing bodies should actively seek to achieve long-term and short-term partnerships with the technology and data suppliers (WEF 2018). At first the Public-Private Partnerships (PPP) can be delivered through selling outcomes to the end users, rather than technology, and drive growth via use cases. The actors involved should integrate technologies upfront and present a united interface to the end user actively cooperating and sharing data with other partners and monetize collateral benefits. Long-term horizons will improve the negative effects of fragmentation leading to the higher confidence of the consumer. Furthermore, prompt establishment of data governance standards for ownership, privacy, usage, and sharing is a central pillar of the partnerships because it builds the mutual trust between the partners and the society.

Data ownership is one of the most quarrelsome topics in the smart city context. Some point out that data should be owned by the end user and not the intermediary. Early agreement of data ownership can help resolve potential problems with transparency and mutual trust. The basis of data governance entails stakeholders to receive informed and meaningful consent from consumers/end users. That should be ensured before collecting data. While data ownership is especially important in healthcare, safety and security and urban mobility dimensions of smart city, the environmental data on heat and air quality is less problematic as it informs about environmental condition of a city. Moreover, partnerships can also emerge between different cities on different scales. Cities can learn from each other in terms of use-cases, support each other though smart cities alliances but most importantly, smart city concept does not end with the border of the city. Connecting regions and different municipalities creates an opportunity for extending the IoT technology cross city borders. Municipality of Rotterdam has actively been searching for intra-regional collaborations recognizing the value of regional partnerships as well as PPP. Moreover, KPN has been collaborating with the municipality of Rotterdam delivering RUGGEDISED project among others. KPN can serve as a key actor involved in delivery and execution of a sensor-based network for monitoring of air quality and heat in Rotterdam.

2. Funding

One of the main constrains when delivering smart city framework is funding. On this occasion Barcelona can serve as the example, where the main barrier for further development of the Sentilo project is lack of sufficient funding. Singapore's Smart Nation Vision is fully funded by the Singaporean Government. Singapore did not allocate any specific budget for the Smart Nation Vision and the costs of initiatives are calculated per department (Keon et al. 2016). The availability of funding allowed the nation-city to develop multiple initiatives. Nevertheless - so far successful – self-funding might not be sufficient, if further and more expensive projects will be in place. Securing the funds for a smart city framework is a *condictio sine qua non*. The system can be delivered in different forms, depending on the needs of the city and the agreements between the partners. Cities can either buy the technology and develop the IoT platform internally (Singapore) or lease the technology subscripting to the services of an external company (i.e., Cisco Kinetic) that will provide necessary infrastructure for solution implementing. This should be determined at the very beginning of planning phase since it will define a long-term city's smart strategy.

3. Data security

Rising concerns about data security deeply influence the topic of smart city deployment. The interconnected city services with the network of sensors, data analytics and decision makers exhibit lack of systemic cyber resilience which might cause severe disruptions putting at risk safety and security of the citizens. Some faculties (i.e., like lack of encryption and patching over the wire) are already known, but alongside IoT development new challenges arise. Security of the smart city will depend on the collaboration between vendors, device manufacturers and governments. It is crucial to ensure more rigorous regulations around IoT security adopting standards and guidance to guarantee that the system is safe and flawless. Additional research into data security is advised in Rotterdam upon completion of the IoT monitoring project.

4. Appropriate story telling

The proposed solutions are delivered for the urban settlers, who need to understand the purpose of the smart solutions. Good and convincing narrative of the problem is crucial to receive public approval, informing the society about the threats and potential solutions. The solutions that use public surveillance or gather personal data must be clearly defined and presented in a comprehensive way. The society needs to be informed about what data is gathered and how is it used by different actors. Building trust between the society and policymakers takes time, and that needs to be accounted for when designing the smart city strategy.

5. Data-driven action

Data is the most important pillar that defines smart cities. Thus, data-driven actions define the decision-making process based on actual data instead on intuition or observation alone. In such complex systems like cities, the data needs to be gathered and analyzed to deliver impeccable solutions that answer the urban problems. The data driven action can be delivered in an automated manner so the IoT system can adjust some urban parameters (i.e., traffic lights) thanks to sounder M2M communication or directly sending the notifications to policymakers who then decide what to do with the data.

6. Learning curve & Feedback loop

Each smart city is different, having different problems and strengths and therefore there is no uniform solution for all the cities. Learning curve addresses the way cities learn by practice, implementing solutions and learning throughout its execution. The more solutions a city implements the faster it learns and therefore becomes more advanced in terms of the technology and good practice. Barcelona is the example of a city that started the implementation of a smart strategy early on, becoming a leader of smart solutions. Therefore, cities should actively invest in the smart technology assuming significant improvements in the future.

[The end]

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Appendix

1. Interviews take-aways

Nr	Expert	Key take-aways
1	Feiko Goter (KPN/)	Lack of integration between parties (government, society, private sector) Various technologies in place (no uniform system for smart cities Privacy: Data sensitive society – societal concern Technology is in place LoRa is already in place Creation of digital Twins of the cities is an opportunity Data sharing is crucial for feasible implementation of the concept First set up a middle layer (all the sensors will be connected, and data will be coming to)
2	Dennis Groot (KPN)	Trust issue within the parties (no one trusts the private – multilevel problem) Data plays a key role of future development and improvements of the cities
3	Jean-Pierre Beunen (KPN)	(no) Budget allocation for large upscaling Process of European tendering Lack of Standardization of solutioning Complex of knowledge within municipalities Privacy rules (for instance: cameras in public spaces)
4	Edwin Deiner (Huawei)	Digital Twin of digital operations can have multiple functions: security, easier daily operations of city.

		Stakeholder collaboration is key to design together a journey to digital transformation
5	Rob Schmidt (Rotterdam municipality)	Ambition of the deputy major to be digital example Digital city 2025 digital example for 2025 The fact that Rotterdam was chosen a smart city in 2012 (top 10 smart cities – with no smart city program)? People was already involved before the digital cities recognizing the importance of smart cities. In 2017 Dutch national movement that organized smart city program. Not only the strategy but also development of a plan 5 biggest cites in NL started (8 or 10 different ROBS) Economic and internalization focused groups. Boost was that last few years municipalities, cities and corporation to smart city Barcelona event knowledge sharing, working was done.
6	Jordi (Barcelona Municipality)	The main contributor of NO_2 in Barcelona is traffic (60% of contribution). According to actual stadistics they are 19.822 sensors already deployed. The network of sensors give the opportunity to capture the state of the city in real time, providing informationa about mobility, metheorology, temperature, noise and many other environmental topics. As an opportunity, the actual sensitisation and awareness of population about air quality and urban heat. The main barrier it could be the lack of budget for implementing a wide Smart City concept.
7	Noman Ahmed (Smart ends)	Air quality sensors are more expensive Cost effective sensors 100eu/piece can be custom-made and easily deployed
9	Yannis (TU Delft)	Still early stage 5-10 years for development Rising awareness, other cities are considering smart lampposts (Utreht now 32 air quality sensors and temperature -> planning to incorporate 60 000)
10	Wouter de Vires (KPN)	Complex system Prepare minimal viable project, Start with clear objective clear algorithm, Digital twin being able to simulate something that does not generate a problem shifting.
11	Frank Vieven – Project manager Smart city and digital economy	Rotterdam is in its intentional stage The biggest problem of Rotterdam's smart strategy is diverse technology used delivered by diverse actors that cannot be easily interconnected.

Table 1. Key take-aways from interviews.

2. Case studies:

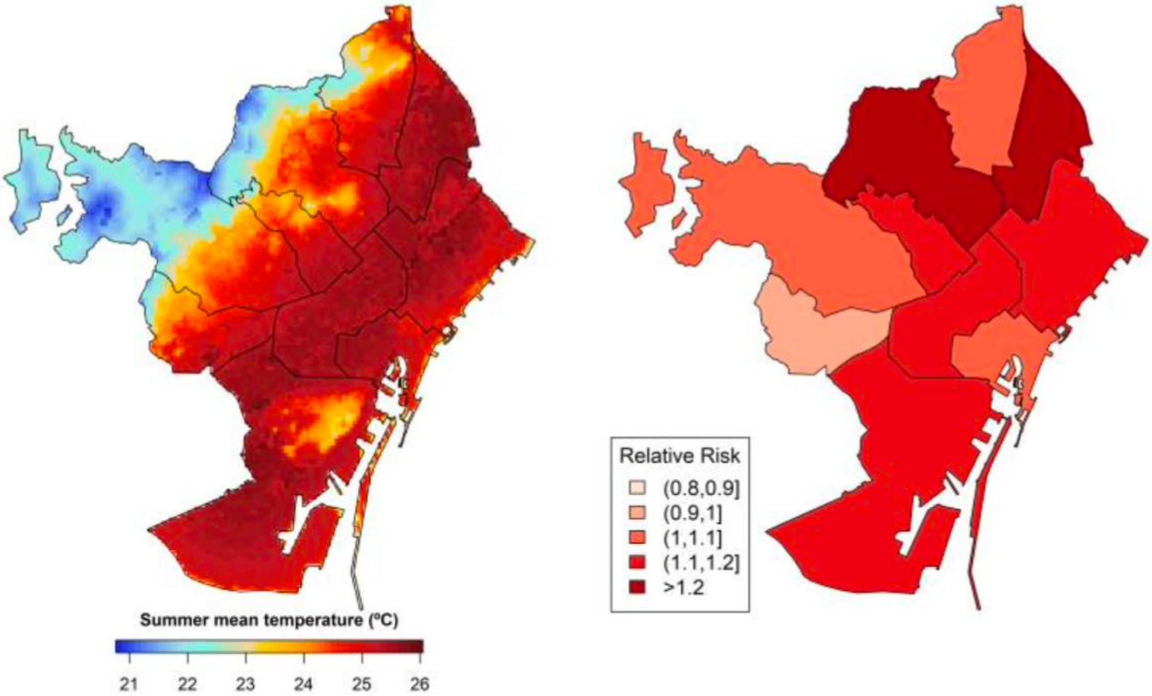


Fig 1. Barcelona temperature distribution and high risk area

	Annual premature deaths in Copenhagen
Fine particles from all pollution sources *(Fine particles from sources in the city)*	500-600 *(65-70)*
Ultrafine soot particles from city's traffic	300-500
All particles (fine and ultrafine soot particles)	800-1100
Road deaths in Copenhagen	10-15

Fig 2. Premature deaths in Copenhagen due to PM pollution vs. road deaths for comparison

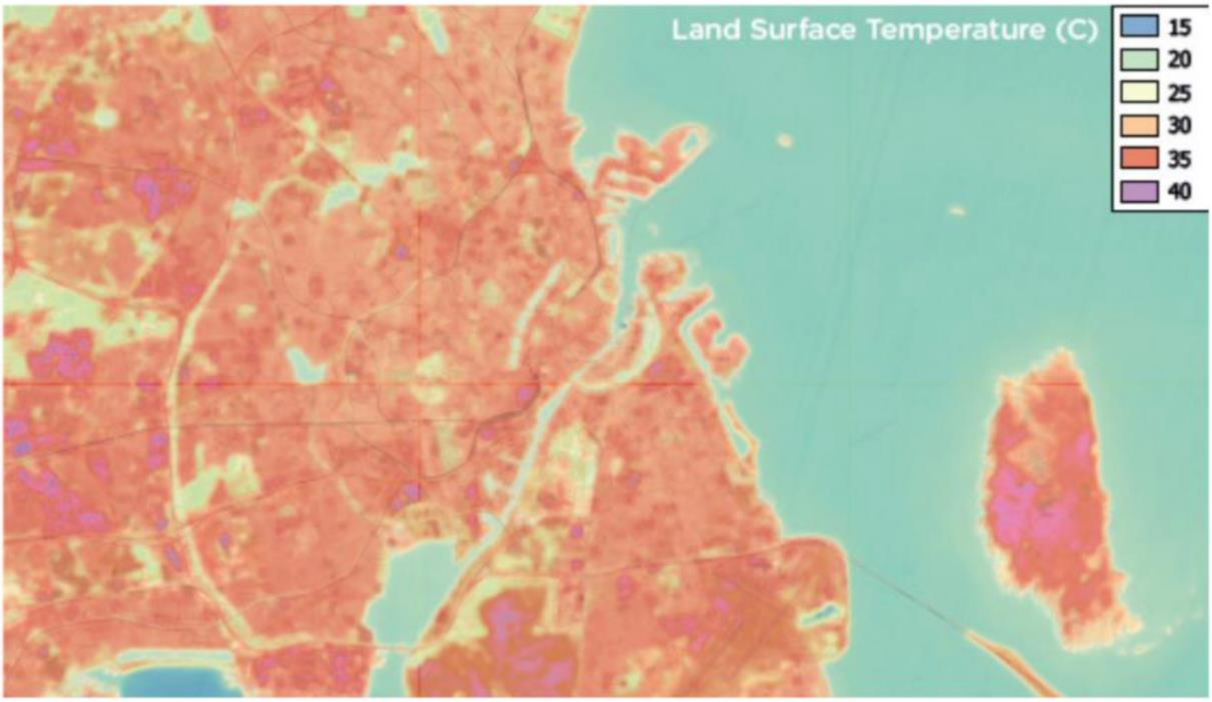


Fig 3. Copenhagen temperature distribution

Sensor typology in Barcelona

Id	Name	Description
temperature	Temperature	Temperature measurement
noise	Soundmeter Class II	Sound level measuring class II.
noise_class_i	Soundmeter Class I	Sound level measuring class I
anemometer	Anemometer	Wind Speed measuring
humidity	Humidity	Humidity measuring
parking	Occupation parking	Occupation parking control
luminosity	Luminosity	Luminosity measuring
container_volum	Occupancy container level	Occupancy container measurement
container_overturn	Container overturned	Container overturned indicator
container_open	Container open	Container opening indicator

Id	Name	Description
status	Sensor status	Status control
battery	Battery level	Battery level measurement
soil_moisture_15	Soil moisture 15 cm.	Soil moisture measurement
soil_moisture_35	Soil moisture 35 cm.	Soil moisture measurement
park_meter	Parking meter	Parking meter control
vehicle_volume	Number of vehicles	Measurement of number of vehicles
vehicle_occupation_average	Average occupancy	Measurement of average occupancy in vehicles
vehicle_speed	Speed Vehicle	Vehicle speed measurement
air_quality_no2	NO2	Nitrogen dioxide measurement
air_quality_pm10	PM10	Measurement of suspension particles PM10
air_quality_pm25	PM25	Measurement of supsension particles PM25
air_quality_o3	O3	Ozone measurement
air_quality_so2	SO2	Sulfur dioxide measurement
air_quality_co	CO	Carbon Monoxide measurement
air_quality_co2	CO2	Carbon dioxide measurement
people_flow	People flow	Measurement of pedestrian flow
flowmeter	Water flow	Water flow measurement
eto	Evotranspiration	Evotranspiration measurement
pluviometer	Pluviometer	Rain measurement
rain	Rain gauge	Rain indicator (it's raining/it's not raining)
wind	Wind gauge	Wind indicator (>X m/s)
wind_direction_6_m	Wind direction	Wind direction at 6 meters

Id	Name	Description
wind_direction_10_m	Wind direction	Wind direction at 10 meters
active_power	Active power	Active power measurement. Units: kilowatts (kW)
reactive_power	Reactive power	Reactive power measurement. Units: reactive kilovoltiamperis (kvar)
cosphi	Power factor	Sensor that relates the active and reactive power. No units
active_energy	Active electrical energy meter	Measurement of accumulated active power. Units: kWh.
global_solar_irradian ce	Global solar irradiance	Mesurement of solar irradiance
leaf_moisture	Leaf moisture	Leaf wetness
oxygen	Oxygen	O2
solar_radiation	Solar radiation	Solar radiation
voc	Voc	Volatile Organic Compounds
temperature	Temperature	Soil/Water temperature
atmospheric_pressure	Atmospheric pressure	Atmospheric pressure
methane	Methane	CH4
ammonia	Ammonia	NH3
redox_potential	Redox potential	Oxidation Reduction Potential
air_pollutant	Air pollutant	Air pollutants-I (NH3, SH2, ethanol and toluene) and air pollutants-II (H2, CH4, CO, ethanol and isobutane)

Table 3 Sensor typology in Barcelona. Out of 90, only relevant to the research displayed.

AoT sensors

Measurement	Purpose/Application	Sensor(s) Used
Carbon Monoxide	Air Quality/Health	SPEC Sensors 3SP-CO-1000
Hydrogen Sulphide	Air Quality/Health	SPEC Sensors IAQ-100
Nitrogen Dioxide	Air Quality/Health	SPEC Sensors 3SP-NO2-20

Ozone	Air Quality/Health	SPEC Sensors 3SP-O3-20
Sulfur Dioxide	Air Quality/Health	SPEC Sensors 3SP-H2S-50
Air Particles	Air Quality/Health (PM 2.5 to ~40)	Alphasense OPC-N2 (included in ~20% of 2018 nodes); Plantower PMS7003 (all 2019 nodes)
Barometric Pressure	Weather Conditions	Bosch BMP180
Humidity	Weather Conditions	Honeywell HIH4030, Honeywell HIH6130, Measurement Specialties HTU21D, Sensirion SHT25
Temperature	Weather Conditions	Honeywell HIH6130, Measurement Specialties HTU21D, STMicroelectronics LPS25H, U.S. Sensor PR103J2, Sensirion SHT25, Bosch Sensortec BMP180, Measurement Specialties TSYS01, Texas Instruments TMP112 & TMP421
Physical Shock/Vibration	Detect heavy vehicles, shock to street pole (e.g. accident)	Freescale Semiconductor MMA8452Q
Acceleration and Orientaion		Bosch BMI160
Magnetic Field	Detect heavy vehicle flow	Honeywell HMC5883L
Infrared Light	Cloud cover, sunlight intensity	AMS-TAOS USA TSL206RD
Light	Cloud cover, sunlight intensity	LAPIS Semiconductor ML8511, Melexis MLX75305
Ultraviolet Intensity	Cloud cover, sunlight intensity	Silicon Labs Si1145
Visible Light	Cloud cover, sunlight intensity	AMS-TAOS USA TSL250RD, Avago Technologies APDS-9006-020
RMS Sound Level	Sound intensity (loudness)	Knowles SPV1840LR5H-B
Camera	Street conditions, traffic flow, events	ELP-USB500W02M-L 170, ELP-USB500W02M-L 140

Table 4. All sensors included in AoT node.

Sensor Location	Organization	Main influencing factor	NO2	NO	O3	PM2,5	PM 10	SO2
Rotterdam HvHolland	DCMR	industrial measuring station, harbour	X	X	X	X	X	X
Maassluis-Kwartellaan	DCMR	industry and shipping	X	X	X	X	X	X
Vlaardingen-Riouwlaan	RIVM	Road traffic emissions	X	X	X	X	X	
Rotterdam-Hoogvliet	DCMR	City background station	X	X	X		X	X

Schiedam-A. Arienstraat	DCMR	city background station	X	X	X	X	X	
Overschie-A13	DCMR	Street station, road traffic emissions	X	X	X	X	X	
Rotterdam Statenweg	DCMR	street station; road traffic	X	X	X	X	X	
Rotterdam-Schiedamsevest	RIVM	city background station	X	X	X	X	X	
Rotterdam-Zwartewaalstraat	DCMR	city background station	X	X	X	X	X	
Rotterdam-Pleinweg	DCMR	a street station; traffic	X	X	X	X	X	
Rotterdam-Hoogvliet	DCMR	city background station	X	X	X	X	X	
Total:	-	-	11	11	11	10	11	3

Table 5. Air quality stations in Rotterdam.

* Only traditional pollutants measuring system mentioned

Sensor Location	**Organization**	**Main influencing factor**	**PM2,5**	**PM 10**	**No2**	**Temperature**
LTD_41716	RIVM/ Luftdaten	City background station		X	X	X
NBI_SB970	NB-IOT	City background station		X	X	
NBI_SB950	NB-IOT	City background station			X	
NBI_SB938	NB-IOT	City background station		X	X	
NBI_SB943	NB-IOT	City background station		X	X	
LTD_33752	RIVM/ Luftdaten	City background station		X	X	X
LTD_37928	RIVM/ Luftdaten	City background station		X	X	X

LTD_22760	RIVM/ Luftdaten	City background station		X	X	X
LTD_22760	RIVM/ Luftdaten	City background station		X	X	X
USP_Pu520	SLA Pilot Utrecht	City background station	X	X	X	X
USP_Pu519	SLA Pilot Utrecht	City background station	X	X	X	X
16 more sensors is deployed and accounted for						
Total:			3	27	26	13

Table 6 Sensors at samenmetenaanluchtkwaliteit https://www.samenmetenaanluchtkwaliteit.nl/projecten

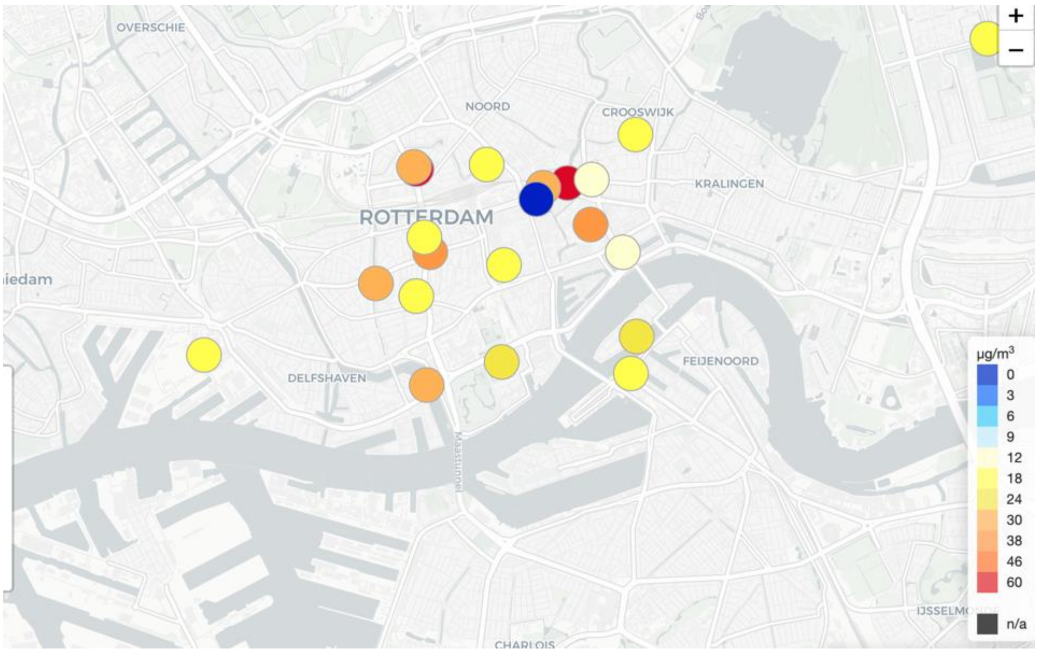
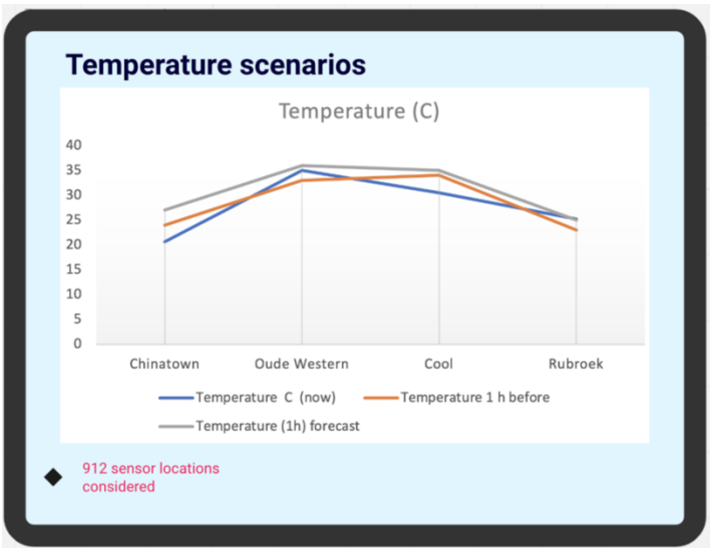
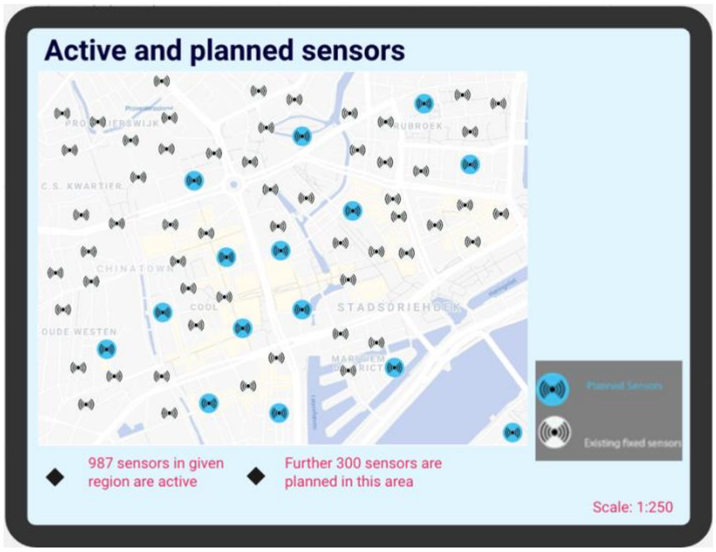


Fig 4 & 5. De Lucht Club interactive map display available at: https://samenmeten.rivm.nl/dataportaal/

Solution proposal – application display





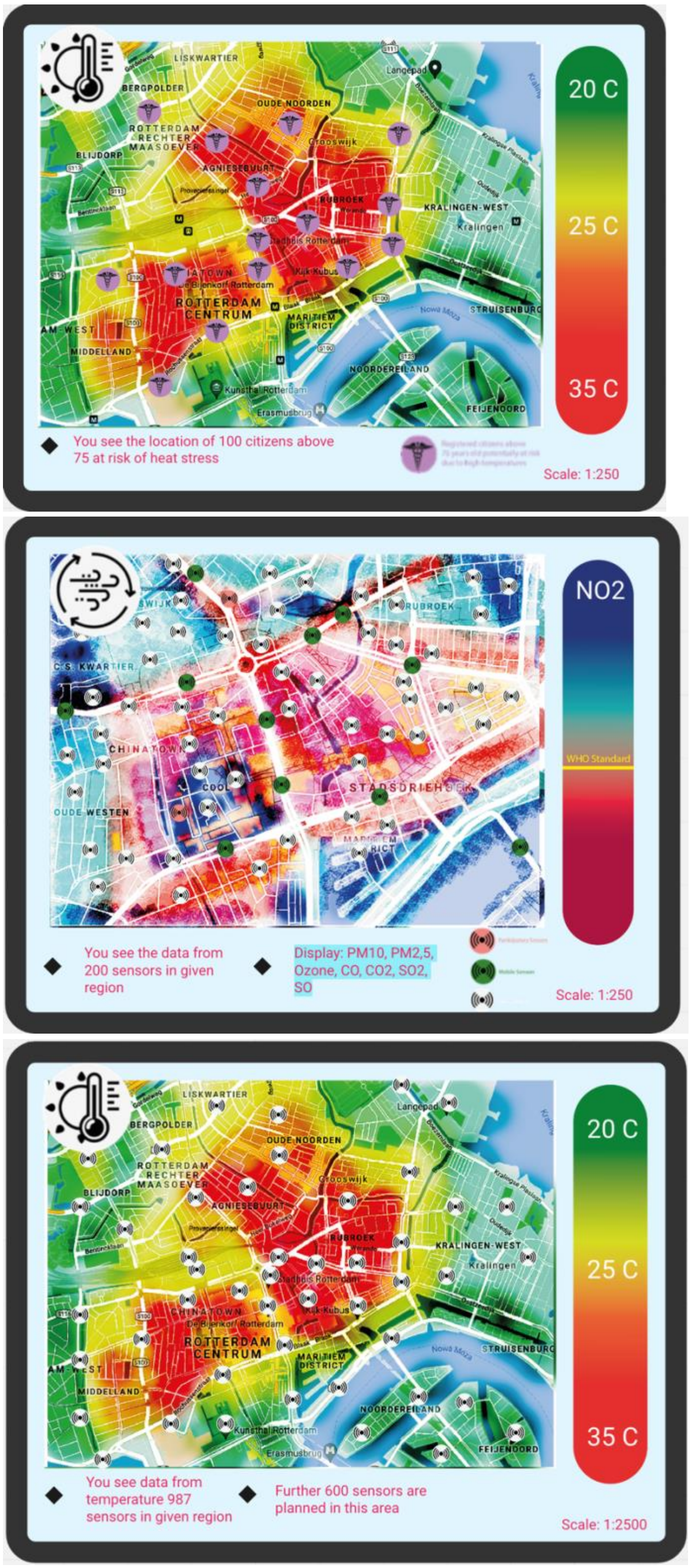


Fig. 6,7,8,9,10 Manager's dashboard.

Evaluation conversation in Miro