Climate Change Adaptation: Internet of Things in Urban Limburg

Exploring the potential and challenges of IoT implementation

BSc thesis by Jakub Kowalski

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Soil Physics and Land Management Group

WAGENINGEN UNIVERSITY
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Climate Change Adaptation: Internet of Things in Urban Limburg

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Study program:
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Student registration number:
1012340

YWU 80812

Supervisors:
WU Supervisor: Dr Jantiene Baartman
Host supervisor: Marc Strookman

Examinator:
Dr. Klaas Metselaar

Date:
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Soil Physics and Land Management Group, Wageningen University

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Abbreviations

CBM - condition-based maintenance
CCAM - climate change adaptation and mitigation
HEMS - home energy management system
IoT - Internet of Things
RSM - remote sensing and monitoring
SBM - schedule-based maintenance
UEM - urban environmental monitoring
UHI - urban heat island effect

Abstract

The impacts of climate change are recognized as a severe threat to human and natural environments by the Dutch national government. Technological innovation in the form of the Internet of Things may be used to adapt to these impacts and to mitigate further emission of greenhouse gasses. To discover its potential role in the National Climate Accord, IoT's potential implementation will be studied in the context of urban Limburg. The southernmost province of the Netherlands was chosen as its urban landscape and recent experience with severe floods lends itself well to the goals of the research. To attain the research objective, this study will first explore the key application point of IoT in urban CCAM. Second, it will assess the challenges of its implementation. Third, it will present various global use cases of IoT. Fourth, it will combine its findings to describe the potential implementation of IoT in Limburg in the form of a policy recommendation.

1. Introduction

1.1 Background

The impacts of climate change have been recognized as a severe threat to human and natural environments by many of the world's governments. The Paris Agreement, as adopted by the United Nations in 2015, attempts to connect the actions of independent governments by setting a clear goal of: "pursuing efforts to limit the temperature increase to 1.5C above pre-industrial levels" (United Nations, z.d.). The Dutch government specifically stated in its National Climate Agreement that the nation envisions a future where its built environment will be well-insulated, capable of generating clean electricity and equipped with renewable heating by 2050 (Ministerie van Economische Zaken en Klimaat, 2019b). Innovation is the key theme of the Knowledge and Innovation Agenda (IKIA) within this Climate Agreement as it will drive all the sectors of society towards their goals of sustainability (Ministerie van Economische Zaken en Klimaat, 2019a). The IKIA wishes to see the application of technologies with the following objectives: (1) contributes towards improvements in quality of life of citizens; (2) facilitates the industrialization and automatization of the production, renovation, construction and installation processes; (3) implements radical changes in the value chain to realize the desired acceleration of the energy transition in the built environment.

The World Economic Forum recognizes the Internet of Things (IoT) technology as a great step towards the digital transformation of our environment. In this transformation, billions of networked objects will attain a level of digital intelligence and autonomy by collecting and sharing of data through the internet (Marchant, 2021). IoT is seen as the key driver of the effort to create sustainable smart cities which add digital intelligence to urban systems to respond more effectively and dynamically to the needs of their residents. The practical examples of IoT implementation are in monitoring, machine learning and automatization. For example, wireless sensor networks (WSNs) have already been implemented in rural Vietnam to remotely monitor sand movement, manage temperature control and predict future movement based on measured wind speed (Anh Khoa et al., 2020). This resulted in improvements to crop yields and an enhanced quality of life for farmers threatened by sand encroachment. IoT may have even greater benefits in the urban environment due to its population and infrastructure density. Woetzel et al. (2018) identified many urban uses of IoT such as: smart streetlights, leakage detection, optimization of waste collection and more. Data collection, future prediction and automatization or remote control are all vital parts of these urban systems. Based on these examples, IoT can be seen as relevant for the goals of the Dutch Climate Agreement as it has the potential to touch upon all aspects of society ranging from the management of public spaces to climate adaptation and optimization of services (Schwab, 2017). If applied with the goal of reducing greenhouse gas emissions and thus slowing the rise of global temperatures, IoT could even contribute towards achieving the main objective of the Paris Agreement (Abd El-Mawla et al., 2019).

While the scope of the emerging IoT technology may be nearly limitless in its potential applications, there are always tangible challenges to innovation that must be overcome. Even one of its great proponents, the World Economic Forum, admits that the vast majority of IoT projects fail, although the organization attributes it to a lack of strategic focus and roadmaps (Li & Russo, 2018). Some of the faults which prevent the adoption of IoT are intrinsic to the technology itself while others are extrinsic, a part of the external systems that IoT aims to affect. In practice, both types of faults often strengthen themselves although their severity is often highly context dependent. Especially in the urban environment, there is a lack of research regarding the faults of IoT systems as it is a constantly evolving technology. Amon et al. (2020) identifies rapidly growing privacy and human rights concerns as the primary obstacles in the further adoption of the technology. These concerns are often based on IoT's primary trait, extreme connectivity between devices and platforms, as also its greatest flaw because it opens the way for external, malicious actors to steal data or disable infrastructure on a large scale. The challenges of IoT must be viewed in their context to be fully understood and evaluated.

To discover the potential role of IoT in the Dutch government's Climate Agreement, the challenges of the country must be first examined. The case of Limburg is especially relevant as recent events have put it at the forefront of the climate change discussion in the country. The region experienced severe floods in July 2021 which were attributed to the extreme rainfall that is expected to be become more frequent due to climate change (KNMI, 2021). To minimize future damages, the local governments strive to become more climate adaptive which may go hand-in-hand with digitalization as Limburg also aims to transform itself into one of Europe's smart regions by 2030 through the s-Lim initiative (MyCSN, 2021). The initiative aims to promote the implementation of IoT systems to collect and share data with the greater goal of improving society. The vagueness of this goal is indicative of the larger uncertainty about the exact role and scope of IoT in the urban environment. The initiative neither addresses the concerns around IoT implementation which must be confronted to prevent potential societal harm.

This study aims to provide background knowledge and insights about the implementation of IoT in urban climate adaptation and mitigation (CCAM) in Limburg in the form of policy recommendations by analyzing the key aspects of the technology, identifying its primary challenges and exploring the use cases that best exemplify IoT's potential contributions towards CCAM.

1.2 Research objectives

The overarching goal of the research is to: "provide background knowledge and insights about the implementation of IoT in urban climate adaptation and mitigation (CCAM) in Limburg in the form of policy recommendations by analyzing the key application points of the technology, identifying its primary challenges and exploring the use cases that best exemplify its potential contributions towards CCAM." It can thus be subdivided into four secondary goals:

1. Provide insight into the key points of IoT application in urban CCAM.
2. Identify the common challenges of implementing IoT in urban CCAM.
3. Explore global use cases of IoT in urban CCAM.
4. Provide insights about the potential for implementation of IoT in urban CCAM in Limburg.

1.3 Research questions

The main research question is: "What is the potential for implementation of the IoT technology into urban CCAM goals of smart cities in Limburg?" It can be further subdivided into four secondary research questions:

1. What are the key points of IoT application that contribute towards the goals of CCAM in Smart Cities?
2. What are the main challenges of implementing IoT in CCAM in Smart Cities?
3. What are the use cases that best exemplify the contribution of IoT towards CCAM in Smart Cities globally?
4. What are the potential implementations of IoT in CCAM in the context of emerging Smart Cities in Limburg?

1.4 Structure of the thesis

The thesis is structured as follows: Chapter 2 contains the descriptions of the study area and the two data collection methods of the study. Chapter 3 first presents the two key concepts of the study: climate change adaptation and mitigation (CCAM), and the Internet of Things (IoT). Second, the chapter connects the two concepts by introducing the key points of IoT application in the urban CCAM. Third, it gives the challenges of application in the urban environment. Fourth, the chapter examines the global use cases of IoT in CCAM. Finally, it presents the main findings from the use cases and gives an outlook for IoT application in urban Limburg. Chapter 4 contains the interpretation of the results, the scientific and societal implication of the research, and the limitations of the study. Chapter 5 concludes the thesis by summarizing its main findings in a set of policy recommendations.

2. Methodology

2.1 Study area description

As indicated by the research objectives and questions, the province of Limburg in the south of the Netherlands was chosen as the study area due to the following reasons: (1) its urban agglomerations, (2) the recent occurrence of severe floods and (3) the researcher's personal contacts in the municipality of Sittard-Geleen. The first cause refers to the three major urban agglomerations of Maastricht, Parkstad and Sittard-Geleen which contain roughly half of the province's population (CBS, 2021). This means that policies and measures which target these urban areas will affect a significant portion of the province's populations. The importance of cities in this region lends itself well to the urban focus of the study. The location of the province within the country is displayed in Figure 1.

The second reason refers to the occurrence of severe floods in June 2021 which affected Southern Limburg with estimated damages in the range of €300 to €370 million (Expertise Netwerk Waterveiligheid, 2021). The primary cause of the floods was the extreme rainfall which occurred on July 13th and 14th that was measured as equaling 182 mm in municipalities such as Ubachsberg over the 48-hour timeframe. Areas such as Valkenburg were particularly hard-hit with extreme damages to the town's center. The floods make Limburg a significant location to this study as they put climate change adaptation as the main topic of discussion in the local governments. There is a strong demand in the province for innovation in the domains of urban design and water management to minimize the chances of an event with such severe consequences ever occurring again.

The third motive puts additional focus on the municipality of Sittard-Geleen in Limburg as the researcher's personal contacts in the area offer additional opportunities for in-depth analysis. The municipality was also less severely impacted the aforementioned floods than the towns which lie in catchment area of the Geul as seen in Figure 2 (Expertise Netwerk Waterveiligheid, 2021). Despite this fact, Sittard-Geleen is still an extremely relevant example of developments in the CCAM as the municipality aims to become a smart hub of the province by 2030 (Gemeente Sittard-Geleen, n.d.). The local government envisions a healthy and sustainable urban environment that is created through cooperation between the four actor groups of the Quadruple Helix: government, industry, academia and residents. The first organization, s-Lim, which supports these goals was already mentioned in the introduction. Brightlands is the second initiative with a campus in the industrial area of Chemelot in the municipality (Brightlands, n.d.). Their focus lies primarily on fostering a community of entrepreneurs and researcher who create sustainable solutions in the industrial sector. The third group is the Future City Foundation which fits the goals of the research best of the three initiatives. The

Figure 2 Provinces of the Netherlands with Limburg highlighted. Adapted from: https://mapsof.net/netherlands/provinces-of-the-netherland?image=full

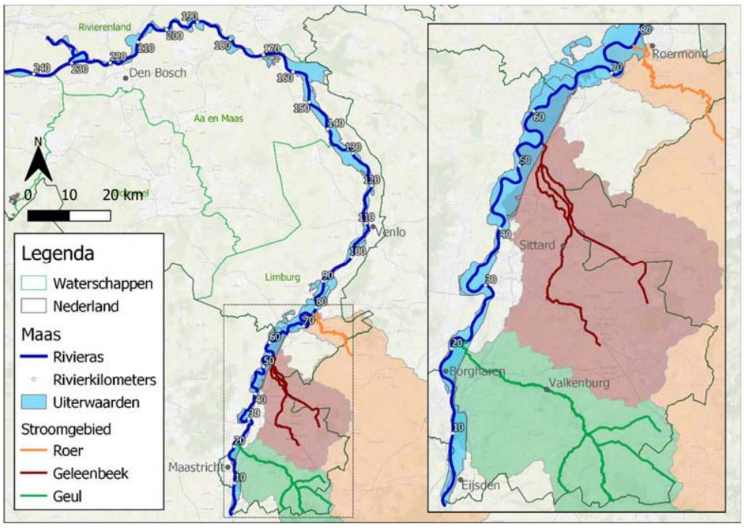

Figure 1 Catchment areas of the rivers Rhine, Geleenbeek and Geul in South Limburg (Expertise Netwerk Waterveiligheid, 2021, p.18)

Foundation is primarily concerned with the digitalization of the urban environment and addressing its challenges such as privacy concerns (Future City Foundation, 2019).

2.2 Literature study

The study's main methodology was the study of literature and information available on the internet. The 'snowball' method was heavily utilized to obtain more relevant data. The following online sources were used:

- Academic articles and reports were obtained from: the online library of Wageningen UR (https://www.wur.nl/en/library.htm), Scopus (https://www.scopus.com/) and Google Scholar (Google Scholar)
- Documents, reports and articles from private organizations were obtained from: Future city Foundation (https://future-city.nl) and McKinsey & Company (https://www.mckinsey.com)
- Government documents, reports and articles were obtained from: Gemeente Sittard-Geleen (https://www.sittard-geleen.nl/Inwoners), Provincie Limburg (https://www.limburg.nl) and KNMI (https://www.knmi.nl/home),

The following Boolean combinations were utilized as search terms: (1) "iot AND climate", (2) "urban AND adaptation", (3) "iot AND renewable", (4) "monitoring AND flood", (5) "internet of things AND energy", (6) "iot AND security"

2.3 Semi-structured interviews

The literature study was supplemented with a set of eight interviews with experts of varying expertise ranging from water management to remote sensing. The interviewees were selected based on their professional and academic history with a preference for individuals with substantial experience in the fields of urban design, land and water management, monitoring and digitalization. Care was also taken to select persons with substantial knowledge about the study area whenever possible. The profiles of each interviewee are available in Annex A.

The contact information of each person was obtained either through their organization's website or forwarded by one of their colleagues. The participants were invited through email with a short description of the research background, goals and questions. The interviews were conducted online through Microsoft Teams in conversations ranging from 30 to 90 minutes for each interview. The final email response rate was 50% and the interview acceptance rate amounted to 29%. The six persons who directly declined to participate in the interviews gave one of the following two reasons: lack of time and type of expertise not fitting within the scope of the research. In 4 cases, the people who declined, forwarded the invitation to their colleagues. It was concluded that 8 interviews were sufficient to reach 'data saturation' which is the point at which no new themes are expected to emerge during continued data collection (Morse, 1995).

This data collection method was performed in the form of online, semi-structured, "face-to-face", in-depth interviews. This form was chosen with the goal of collecting open-ended data and exploring the thoughts of each interviewee about a particular topic. The preparation of the general interview structure was performed according to the guidelines as set out by DeJonckheere and Vaughn (2019). The custom interviews were prepared first by careful study of each participant's background. This information was then used to customized the generic set of questions present in the interview guide (see Annex B). Care was taken to ensure that the interview structure would build trust between the researcher and interviewer to facilitate in-depth conversation.

This was achieved by first introducing the researcher's goals and ambitions regarding the study. The interviewee was then invited to describe their academic and professional background regardless of its relevancy to the research questions. Afterwards, the conversation was steered towards the topic of IoT and CCAM in the urban environment. The asked questions were primarily related to the secondary research questions two and four. Many of the interviewees had personal experience with IoT implementation and they could offer unique insights about the challenges of its implementation and the outlook for IoT in

Limburg. The interviews were closed by asking for permission to include each interviewee's name and their expressed opinions in the study.

3. Results

3.1 CCAM and data in urban design

To truly understand the relevance of IoT in urban CCAM, both concepts must be first carefully defined and analyzed in the appropriate context. CCAM consists of two types of action: adaptation and mitigation. Adaptation refers to the "adjustment to the actual or expected climate and its effects (IPCC, 2014b, pp. 118). On the other hand, mitigation is "a human intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC, 2014b, pp. 125). Combined, they form an umbrella term which contains a significant part of actions that aim to address climate change.

Climate adaptation is often intertwined with ensuring human comfort through the control of urban microclimate factors such as: temperature, wind, precipitation and air quality (Lenzholzer, 2013). Temperature in the form of thermal comfort is the most interesting due to the sheer amount of relevant parameters that can be measured and affected through design measures: air temperature, humidity, shortwave radiation, longwave radiation and wind velocity. They must be intelligently controlled as they all contribute towards the urban heat island effect (UHI) which may severely affect public health in the form of heat stress, and energy consumption through air conditioning and refrigeration (Kovats & Hajat, 2008). Urban design may either alleviate or exacerbate these effects.

Adaptation may also ensure human safety through measures which alleviate damages from wind and precipitation. Wind gusts around ill-designed, high-rise buildings can be dangerous on the pedestrian level. Wind comfort assessment during the design phase may prevent this danger, but it is highly data intensive as it requires substantial meteorological and aerodynamic data (Janssen et al., 2013). Pluvial flooding and precipitation go hand-in-hand and they can quickly overwhelm urban drainage, damage infrastructure and cost human lives. Early warning systems are an example of how monitoring and data collection are directly contributing towards human safety. To create these systems, sensors are deployed in strategic locations to predict floods and allow for a more timely response that may minimize the loss of human life and material damages (Sene, 2008).

In practice, mitigation refers mainly to the decarbonization of the electric grid and the optimization of energy consumption. Renewable sources of electricity such as wind turbines and solar panels play a crucial role in this, but their integration in the energy grid is often limited by their intermittency (Leusbrock, 2021). This means that their generation of energy is not constantly of the same quantity. The factors which may influence it are highly context dependent and include anything ranging from the location, weather or season. As found by Gowrisankaran et al. (2011), intermittency is a crucial obstacle in the further adoption of renewable energy sources such as solar panels. Furthermore, optimizing energy consumption is a vital step in the reduction of greenhouse emissions. In the case of the EU, a substantial fraction of the building stock is inefficiently built and needs to be upgraded to attain the 2050 decarbonization goals of various member nations (BPIE, 2017).

Generally, CCAM measures require a highly localized, contextual approach which often demands abundant and reliable information about the area (IPCC, 2014a). The value of urban data is further elevated as cities are "uniquely situated to understand local contexts, raise local awareness, respond to citizens' and civil society pressures, and work to build an inclusive policy space" (IPCC, 2014a, p. 577). Urban environments are the prime recipient for CCAM and should be taken into high consideration as actions in the population-dense cities can affect substantial amounts of people. Remote sensing and monitoring will play a key role in obtaining the necessary data to ensure the success of CCAM measures.

3.2 Conceptualization of IoT

To evaluate the potential of IoT in CCAM in roles such as data acquisition, the technology must be first carefully conceptualized. Similarly to CCAM, the concept of 'Internet of Things' can be explored through the words that compose it. 'Internet' refers to interworking while 'of Things' indicates that it is a cluster of interworking ordinary objects. This interpretation corresponds with the semantic definition as set out by INFSO (2008, p. 4): "a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols". IoT should be seen as a transformative power that may fully integrate people and objects into their surroundings with more efficient management as a result. This goes beyond the classical Internet as IoT helps us to understand the physical environment and enables our systems to react to various stimuli within it (Khanna & Kaur, 2020). As seen in Figure 3, IoT expands the Internet by truly connecting it with devices that enable tracking and monitoring of various phenomena with the potential for automatization of the connected systems.

When reviewed from a more technical perspective, IoT can be separated into four core structural layers as found by Rhee (2016): (1) The hardware layer of sensors, computers and other physical objects such as cars.

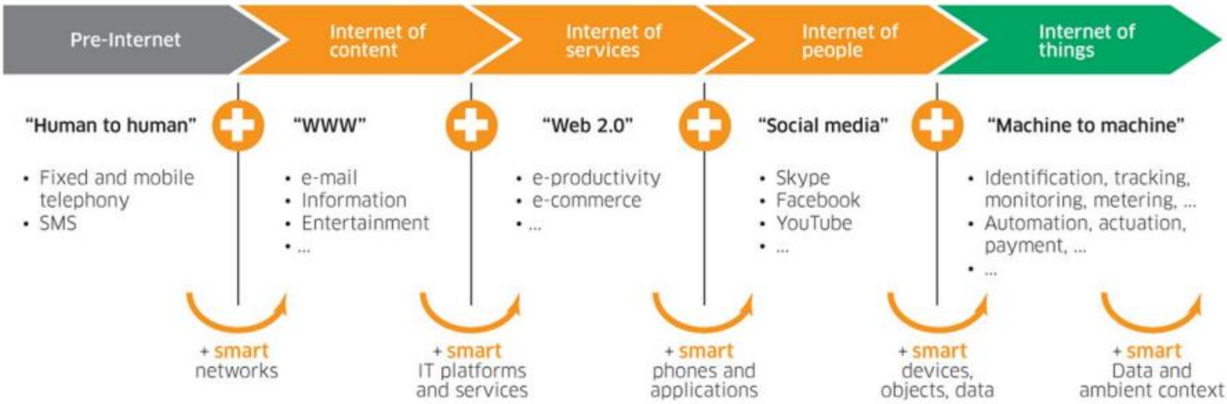

Figure 3 Roadmap of communication from Pre-Internet to the Internet of Things. Sourced from: (Khanna & Kaur, 2020, p.1697)

(2) The communication layer which may be wired or wireless and it may utilize the Internet. (3) The data analytics layer which combines, stores and processes the communicated data. (4) The service layer which involves the human or machine decision-making process. These can be best visualized with the simple example of the first IoT system in 1991 with only a split of the communication layer into two parts. Cambridge University's Trojan Room coffee pot webcam (see Figure 4) was born out of the local researchers' frustration with finding an empty pot of coffee after walking through the large campus building (Stafford-Fraser, 2001). They wanted to view real-time information about the fullness of the pot from the convenience of their workstations. The hardware layer was the pot, camera, spare computer, framegrabber and individual workstations. The camera obtained raw data which was communicated to the spare computer. The raw data was analyzed by using a framegrabber which grabbed a frame at regular intervals. The grabbed frame was then sent to their servers which made it viewable from each individual workstation. Based on the information provided by the frame, the researchers could make an informed decision whether to grab a cup of coffee without wasting their time to find an empty pot. Their decision-making process corresponded to the service layer. During the lifetime of this very first webcam, the data was instead sent to the Internet once browsers could display pictures where it gained notoriety among the early-users.

Figure 4. Trojan Room coffee pot. Retrieved from: https://www.allaboutlean.com/spaghetti-diagrams/trojan-coffee-pot/

The coffee pot was the first hint of the increased functionality and connectivity that IoT could bring in the domain of communication. A more recent and popular application of IoT are wireless sensor networks (WSNs) in remote sensing and monitoring. They contain various types of sensors which wirelessly collect, send, receive and aggregate data to and from other nodes. (Fong, 2016). WSNs are typically deployed in remote areas without convenient access to energy lines as most untethered sensors either operate on batteries or have the capacity to harvest energy through solar panels. This puts them at a large advantage when compared to the fixed sensors as energy lines can be immensely costly in hard-to-reach locations (L. Janissen, personal communication, December 03, 2021). Additionally, the failure of individual nodes in a WSN is seen as inevitable and many networks are designed to cope with this occurrence through self-organization (Athreya & Tague, 2013). These additional functionalities also complicate the architecture of a typical WSN compared to the case of aforementioned coffee pot. The architecture of a typical WSN follows the OSI model which expands the layers with management planes as visible in Figure 3.

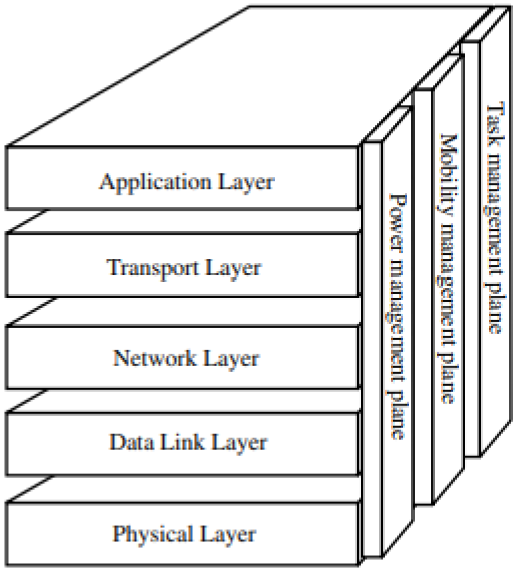

Figure 3 WSN architecture following OSI model. Retrieved from Fong (2016, p. 209)

IoT also goes beyond mere monitoring as it may provide supervisory control over larger systems under the term Condition-Based Maintenance (CBM). As found by Lu & Yang (2016, p. 482), data captured through the IoT can be analyzed to "assess current operation and predict how the state or condition might be in a future time". This may result in greater control over an asset with an improved capacity to correct or mitigate undesirable conditions. This gives a significant advantage over Schedule-Based Maintenance (SBM) where action is performed only according to a schedule irrespective of the asset condition.

IoT has great potential to influence all sectors of our society due to its capacity to connect and imbibe objects with intelligent behaviors. It may give its users greater insight and control over their physical environment which in turn can be utilized towards the goals of CCAM (Kao, 2016).

3.3 Key points of IoT application in urban CCAM

The urban applications of IoT often fall under the umbrella of Smart City initiatives. Although there is no widely agreed-upon definition of the term, a Smart City is characterized by its application of innovative technologies to improve the life of the city's residents (Reichental, 2016). Ensuring human comfort and safety through CCAM is a part of this objective and IoT may contribute towards achieving this. The chapter will provide insights into the key points of IoT application in urban CCAM according to the division into two types of action: adaptation and mitigation.

3.3.1 Adaptation: environmental monitoring and responsiveness

Adjustment to current or expected effects of climate change requires abundant data about the urban microclimate to successfully ensure resident comfort. As found by Reichental (2016), urban design and development must be a deliberate process that is supported by reliable data. Based on the characterization in the previous chapter, wireless sensor networks are an attractive choice for urban environmental monitoring (UEM) with many potential applications.

Temperature is an important factor of the urban microclimate and can improve the data collection process for all its parameters. Measuring the variations between a city's neighborhoods is challenging due to a variety of problems such as strongly heterogeneous land cover or incomplete data coverage (Grimmond, 2007). To overcome this, images are used from polar orbiting satellites and those in geostationary orbit. This method carries its own drawbacks due to the low image frequency of the polar satellites and the coarse resolution of the geostationary ones (Sun & Pinker, 2003). Nor are the retrieved surface temperatures representative of the thermal comfort within cities as they cannot reflect the air temperature or humidity. Stationary sensors are a step above it as they can measure more types of parameters, but they are expensive to deploy over large areas. WSNs in the form of mobile measurement networks (MMN) may outperform both satellites and fixed sensor networks when it comes to data coverage and collection of data (Yang & Bou-Zeid, 2019). An MMN consists of a network of sensors placed on moving objects such as cars, busses or bikes which give a far larger coverage than stationary sensors. In certain cases, both sensors types could be combined hybrid networks as it can combined to ensure both wide coverage and reliably estimate the time span of extreme events.

3.3.2 Mitigation: optimization, integration and reduction of greenhouse emissions

One of the goals of the aforementioned Dutch Climate Agreement was to have a built environment that can both generate green energy and be energy efficient. IoT's ability to enhance data collection and supervision over relatively large systems, can be highly beneficial for this objective. If correctly applied, it may further the decarbonization of the energy grid by better integrating the sources of renewable energy such as solar panels.

The current paradigm of energy optimization within the build environment is heavily restricted by a lack of data about most buildings' energy and maintenance profile (Desogus et al., 2021). Building Information Modelling (BIM) is the first step in answering this by visualizing the energy performance of buildings, but it is still severely limited by the lack of real-time data. Integrating IoT and BIM could result in a new, powerful paradigm where real-time data is used to gain insight about a building's energy profile. As found by Desogus et al. (2021), IoT's low-cost nature and ease of deployment make it highly suitable for data collection in existing buildings with architectural constraints. Wireless sensors are highly preferable because they do not necessitate the costly system modifications that are imposed by wired, static sensors.

The decarbonization of the energy grid and the built environment through IoT involves improvements in monitoring, control and integration of renewable energy into our existing systems. As a significant part of the built environment and a substantial consumer of energy, households are a good and familiar example of these efforts (Tipantuna & Hesselbach, 2021). Generation of green energy through solar panels is increasingly common in households, but the contemporary Home Energy Management Systems (HEMS) fail to fully tackle the aformentioned issue of intermittency. IoT-enabled adaptive HEMS may be the solution as they optimize the usage of renewable energy when it is available. As found by Tipantuna and Hesselbach (2021), IoT enables simultaneous monitoring of at-home energy generation while communicating the demand to the supplier. By fully utilizing the generated energy when available, the adaptive system can reduce the quantity of energy obtained from the supplier.

3.4 Challenges of IoT application in CCAM

As indicated in the Introduction, the challenges of IoT can either be intrinsic flaws of the technology itself or extrinsic obstacles in its adoption. Both can be a considerable obstacle to the application of IoT in urban CCAM and they must be addressed to ensure that the technology benefits the residents of cities. The structure of this chapter will follow the division made between the two types of challenges.

3.4.1 Intrinsic challenges: security, privacy and battery life

Chapter 3.3 showed how many types of applications IoT can have in urban and domestic spaces, but this also makes it an attractive target to malicious actors. The different layers of IoT can be attacked in a wide variety of ways, some of which were identified by Azam et al. (2019) such as: (1) phishing, (2) eavesdropping, (3) data theft, (4) distributed denial-of-service attacks and (5) sleep deficiency attacks. Attacks 1-3 rely on the stealing of information either by obtaining a user's login data as in the case of phishing, or by capturing communicated data as in the case of eavesdropping. This is highly undesirable as it can potentially result in the theft of private information. Attack 4 relies on flooding the servers of an IoT system and thus denying service to its users. Attack 5 disables individual nodes in the hardware layer by exploiting the battery dependance of for example WSNs. The ease of data theft, also results in privacy concerns around IoT as it may open new pathways for malicious actors to exploit the increasing digitalization of the urban environment.

Even when unexploited by hackers, the limited battery life of the wireless parts of an IoT is an obstacle to the longevity of the system. This trait limits the functionality of WSNs as the frequency of measurements is limited to attain a longer lifespan of the sensor (L. Janissen, personal communication, December 03, 2021). The battery can be replaced, but this process may be costly or time-consuming if the sensor is in a hard-to-reach location.

3.4.2 Extrinsic challenges: data overload and lack of expertise

The collection of data is not the only concern in the deployment of a WSN as raw data must be processed into information to be truly useful. As found by Timmerman and Mulder (1999, p. 41): “Monitoring without specification of information needs prior to the actual network design will be a waste of money.” Their research concluded that three crucial elements must be included in a successful design of a data collection network: (1) communication between information producers and users, (2) insight into the involved organizations and their requirements in the process, and (3) a clear structure defining what activities will be performed at what stage of the process. As was mentioned in the Introduction, inability to attain a strategic focus and develop a roadmap may spell the failure of an IoT project. To avoid an overload of unnecessarily collected data, care must be taken to develop a monitoring network with a clear structure and objective.

The process of designing a monitoring network is further challenged by the lack of the necessary interdisciplinary expertise in an organization (R. van Ouwerkerk, personal communication, December 03, 2021). In the case of the Dutch *Waterschappen*, the issue extends over all age groups as highly experienced workers often have issues with adapting to the rapid digitalization of water monitoring. The newcomers to the organization may be experienced in remote sensing and data science, but they lack the crucial insight in water management that allows them to develop a clear purpose for monitoring. In the smaller municipal governments, the problem may lie in the simple lack of manpower. The organization could simply be limited to one expert who lacks the necessary expertise or time to implement a complex monitoring network. Overcoming these obstacles may prove difficult to smaller or less-versatile organizations and finding a solution to this challenge lies beyond the scope this study.

3.5 Application of IoT in CCAM: findings from use cases

Many use cases of IoT were discovered in the course of the study. Four cases were selected to showcase the variety of the technology’s applications in adaptation and mitigation of climate change. In each subchapter, these cases will be described and analyze based on their CCAM goals and utilization of IoT.

Table 1 Studied use cases of IoT in CCAM

Use case	Primary source	Region	CCAM activity	Form of IoT
Flood prevention (SCORE project)	Mishra (2019)	Malaysia	Drainage gully monitoring	Deep learning, IoT-enabled smart camera
Disaster prediction and monitoring	Muslim (2020)	Indonesia	Disaster mitigation	IoT-based climate monitoring system
Automated floodwater detection	Uwayisenga et al. (2021)	Tanzania	Flood monitoring	IoT-based system for early detection and flood warning
Energy consumption optimization	Irshad (2020)	Malaysia	Mitigation of carbon emissions	IoT-based TE-AC system

3.5.1 Monitoring of street drainage obstruction (SCORE project)

Street drainage is a critical part of urban design as it minimizes flood damage and disruption to traffic. A typical street drainage systems function by first collecting excess water from the streets in gutters, then in transports it to storm drain and finally discharges it into a detention basin (UDFCD, 2016).. The collected water often carries litter which may clog the storm drain and negatively impact the functionality of the entire system with flooding as a consequence during severe rain. Currently, the drains are often maintained under schedule-based maintenance which carriers the issues of inefficiency and often untimely cleaning. The potential of IoT for condition-based maintenance could potentially solve this issue.

Gully blockage detection systems are seen as notoriously hard to build using current techniques, and the first use case proposed a novel technique which utilizes deep learning to create an IoT-enabled smart camera to solve this issue as part of the SCORE project (Mishra et al., 2019). Deep learning is a subset of machine learning and in the case of the smart camera, it is utilized to allow for image classification in flood monitoring with a high accuracy. The IoT-enabled smart cameras are made to capture images of drains and classify them according to the severity of the blockage (Figure 5). The project will continue to further research a more precise distinction between the three classes of blockage.

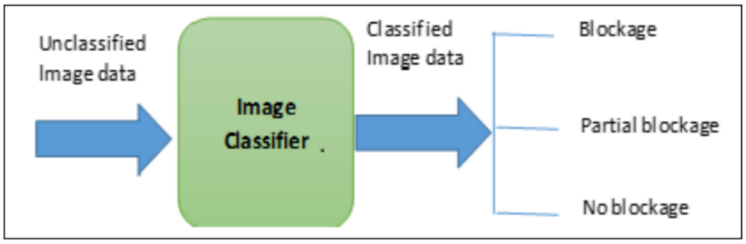

Figure 5 Block diagram of the image classification process. Retrieved from: Mishra et al. (2019, p. 5)

The wider implications of this case are in the improved maintenance of urban drainage. The potential transition from SBM to CBM will alleviate the pressure from municipal workers who are responsible for the regular cleaning of the street drains. The drains will also be better prepared to handle extreme events if they are not clogged.

3.5.2 Monitoring and prediction of floods

Response and recovery after natural disasters have always been a key focus of governments, but there is an increasing push for adaptation which will decrease the potential economic and social impacts of disasters. An example of this are the early warning systems which are already utilized in one form or another by many governments. Their primary challenge is the systematic acquisition of sufficient amounts and types of data over a large area to reliably predict a disaster event such as floods.

Two cases of the monitoring and early prediction of floods were identified during the research. The first case in Tanzania involved the design and testing of an IoT-based system for automated floodwater detection and warning (Uwayisenga et al., 2021). The system could detect water level rise in a bod of water and continuously send real-time updated to the cloud. The data was then automatically evaluated and a rudimentary warning system by SMS was developed. The second case was in Sumber Brantas, Indonesia where researchers installed and IoT-based climate monitoring system which collected and evaluated data for wind speed, wind direction, rainfall humidity, temperature and air pressure to predict storms and send out automated warnings as seen in Figure 6 (Muslim et al., 2021). IoT again allowed for an integrated approach that allowed for the deployment and collection of data from many types of sensor. The collected data was processed and displayed in dashboard to the residents of the village. The monitoring system gave insight to the local residents regarding the state of the weather and potential for natural disasters such as extreme winds or rainfall. Whether the system was adopted and further utilized by the local government is unsure and improbable due to the small population size of the village.

Both cases have interesting application for urban environmental monitoring and potentially natural disaster warning systems. The ability of IoT systems to obtain, combine and process a variety of data is relevant for the adaptation to the increasingly common extreme weather events as they will provide the necessary information to improve both preventative and response actions.

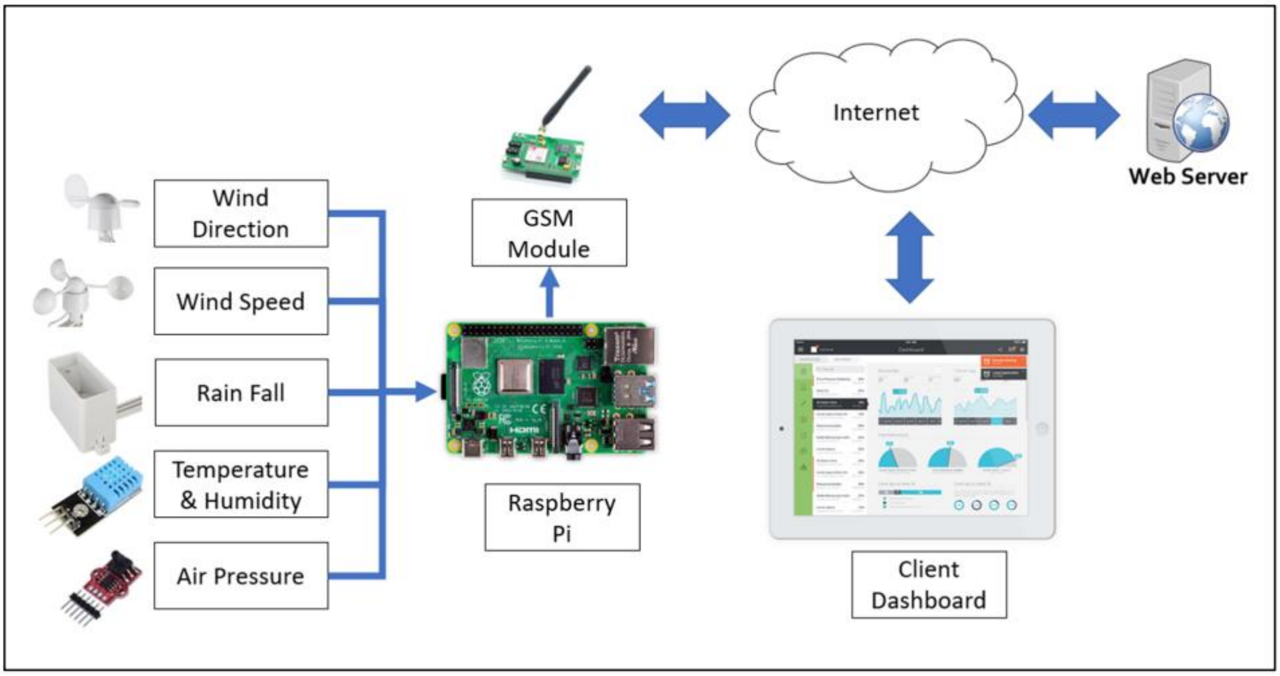

Figure 6 Block diagram of the monitoring system in Sumber Brantas, Indonesia. Retrieved from Muslim (2020, p. 3)

3.5.3 Optimization of energy consumption in air conditioning

The final use case involves the use of IoT system in the optimization of energy consumption in air conditioning and is thus an example of climate change mitigation.

The study investigated the performance of thermoelectric air conditioning in Malaysia where it was smartly controlled using IoT-based configuration increase the performance and efficiency of the system. Both were achieved with an IoT-based thermal management system that automatically adjusts the electricity expenditure through constant monitoring of the testing location

The previously mentioned UHI has an effect on increasing the use of air conditioning and this use case may be an example of a system that could alleviate the potential damages from the further adoption of air conditioning due to the increasing temperatures in the urban environment.

3.6 Outlook for IoT in CCAM in urban Limburg

The potential implementations of IoT in CCAM in the context of the emerging Smart Cities in Limburg will be grouped and presented according to the distinction between adaptation and mitigation. The subchapter will be closed with a policy recommendation aimed at the policy-makers within the province who are concerned with the topics of urban CCAM and digitalization.

3.6.1 Adaptation: environmental monitoring

A recurrent application of IoT in the study is the use of WSNs in environmental monitoring where it enables the coverage of a large area and the acquisition of substantial quantities of data. This function facilitates the adjustment to the effects of climate change in cases such as early warning systems for floods, enhanced maintenance of flood-prevention infrastructure and observation of phenomena such as UHI. In Limburg, IoT can be used for similar purposes as the region recently suffered from floods and seeks an innovative solution to the issues of its cities.

There are challenges however which may slow down the adoption of IoT for these purposes. The issue of security makes it difficult to use IoT for data collection as it is vulnerable to attacks which can disrupts vital services or research performed by government institutions such as the Waterschappen (R. van Ouwerkerk, personal communication, December 03, 2021). The privacy concerns are also issues in certain cases, although this challenge is highly context dependent as many residents are not bothered by non-invasive monitoring systems (T. Turèl, personal communication, November 23, 2021).

3.6.2 IoT-led mitigation: optimization of energy consumption

In certain cases, IoT can also be utilized to optimize the energy consumption and thus reduce the emissions of greenhouse gasses. The case of IoT-managed thermoelectric air conditioning in Malaysia may be relevant for the situation in the Netherlands as a whole due to growing usage of air conditioning in the country. Furthermore, IoT can utilized within the built environment to ensure more efficient consumption of energy and better integration with renewable energy sources.

The primary challenge for policy-makers is the difficulty of affecting this type of change within the private industry.

3.6.3 Policy recommendations for fostering IoT implementation in CCAM

The policy recommendation described in this subchapter will be primarily based on the findings from the interviews and supplemented with literature whenever applicable. The three recommendations for the provincial and municipal policy-makers in Limburg are: reate and support test beds that facilitate experimentation with IoT applications, and promote safety and security in IoT systems from the start.

The first recommendation is especially useful for establishing the initial steps of IoT application in Limburg as it circumvents the challenge of potentially lacking expertise in the domains of ICT and CCAM in the local government itself (K. Broumels, personal communication, November 17, 2021). Consistent support of communication between actors within these test beds and the local government is also crucial (M. Pauly, personal communication, December 13, 2021).

The second recommendation refers to the aforementioned intrinsic challenges of IoT implementation. To ensure that IoT implementation is successfully implemented and beneficial to the resident in the cities of Limburg, the concerns of security and privacy must be addressed (M. Zuniga, personal communication, November 22, 2021) .

4. Discussion

This chapter will discuss the findings of the study, its scientific and societal implications, and the limitations of the research. The study explored the potential of IoT implementation in CCAM in urban Limburg through the study of online literature and interviews. The results showed that IoT may be implemented in this context, but only if the local governments address the intrinsic and extrinsic challenges of its adoption. These findings are primarily relevant to researchers interested in the implementation of IoT in the Netherlands and the policy-makers who wish to learn about the various point of IoT application in urban CCAM in Limburg. While the study underlines the need for policy-makers to provide a solution to the challenges of IoT implementation, it does not list any potential solutions to these challenges.

Further research is necessary to explore the solutions to the challenges of IoT implementation in CCAM. The concerns of security in WSNs may potentially be addressed using a game theory approach as found in the work of Casado-Vara et al. (2018). Additionally, an approach utilizing blockchain has also tested to create a secure and adaptive model for control of IoT networks in the research performed by Casado Vara (2019). These approaches are highly innovative and actual use cases were not identified in the course of the research.

The limitations of the research relate to its data collection methods and the scope of the research. The primary data collection method was the study of online literature which limits the detail in which use cases of IoT in CCAM can be studied. Urban CCAM is an extremely new application of IoT with a limited quantity of academic literature. The available documents sourced from business and government institutions also rarely explored the aftermath of IoT implementation in CCAM and primarily focuses on projects in their initiation phases or they describe the need for an IOT-based solution.

The second data collection method, the interviews, limit the study due to three possible factors: selection criteria of the interviewees, bias of the researcher and the flawed estimation of the data saturation point. The selection criteria were initially chosen to ensure a selection of interviewees with diverse background. Upon review, the selected group does not succeed in representing all valuable actor groups in urban design as the majority of interviewees consists of government employees. The findings of the interview also cannot be generalized to any group, even municipal workers, other than the persons directly studied.

It also necessary to point out the inherent bias of the researches which may skew the findings from the interviews. The researcher's background in international land and water management, and personal experiences as an intern in the municipal government of Sittard-Geleen have the potential to further reduce the objectivity of the data obtained through interviews. This concern is further enhanced by the aforementioned low diversity of background among the interviewees which often directed the interviews towards the issues of water management.

The data saturation point was also estimated after no new themes emerged in the final interview. The potentially wrongful estimation of this point may be caused by the high amount of interviewees with a background in water management. If a more diverse group was contacted, the point of data saturation might have been estimated far later and thus resulted in a larger quantity of collected data.

5. Conclusion

The key point of IoT application in urban CCAM were identified as environmental monitoring and the optimization of energy consumption. In adaptation, IoT can enhance data collection and contribute towards gaining more insight about the urban environment and obtaining data which may support solutions to urban challenges. Additionally, IoT can be utilized towards improving the preparation and responsiveness to floods by gathering data for early warning systems and the schedule-based maintenance of crucial infrastructure.

There are challenges to the implementation of IoT in urban CCAM and they can be divided into two groups: intrinsic and extrinsic. The intrinsic challenges relate to the issues that are inherent to the technology itself such as its security and dependance on batteries. IoT systems are vulnerable to malicious attacks from hackers which may results in the theft of personal data or denial of services to the system's users. The vulnerability of IoT is also directly related to the challenge posed by privacy concerns. Due to the possibility of theft of personal data, many people are worried about the adoption of IoT as it may offer additional opportunities for malicious actors to exploit the digitalization of the urban environment.

The extrinsic challenges refer to the issues around the adoption process of IoT by various organizations which may lack the necessary expertise to successfully design a useful monitoring system or implement it. Collection of data is only the first step in solving issues inherent to the urban environment as data must be processed into information to be useful. To achieve this, three crucial elements must be part of the design process: (1) communication between information producers and users, (2) insight into the involved organizations and their requirements in the process, and (3) a clear structure defining what activities will be performed at what stage of the process. Without these elements, data may be collected but it will not be utilized towards the practical goals of CCAM. Following this design process successfully demand large amount of inter-disciplinary expertise which many organizations are unable to provide. It is crucial that the designers posses both knowledge about the technology itself and the issues it aims to resolve. Especially smaller organizations cannot muster enough manpower to fulfill this demand.

The studied global use cases of IoT reaffirmed its potential role in environmental monitoring as WSNs offer great benefits to the data collection process. Their ease of deployment and lack of dependance on wired connection makes them an important tool in areas such as early flood warning or the monitoring of vital infrastructure. IoT may also be utilized to optimize the energy consumption of various systems such as air conditioning.

IoT has a great potential to be implemented in CCAM in urban Limburg, but first its challenges must be addressed by the local governments. To attain this, the following approaches should be taken: First, local governments should create and support test beds that facilitate experimentation with the technology. Second, they should promote safety and security in IoT systems from the start of its implementation.

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Annex A

Table 2 Profiles of the eight interviewees

Interviewee	Role in organization (self-described)	Organization	Areas of expertise (self-described)	Date of interview (dd-mm-yyyy)
1) K. Metselaar	Associate Professor (Universitair docent)	Wageningen UR	Ecology, hydrology and green roofs	12-11-2021
2) K. Broumels	Advisor Information Management (Adviseur Informatiemanagement)	Gemeente Sittard-Geleen	Smart Cities, digitalization and information management	17-11-2021
3) M. Zuniga	Researcher	AMS Institute	Internet of Things, visible light communication, cyber physical systems	22-11-2021
4) T. Turèl	Program manager	AMS Institute	Responsible sensing, politics of sensing and metropolitan design	23-11-2021
5) R. van Ouwerkerk	Senior advisor of Water Management (Senior Adviseur Watermanagement)	Waterschap Brabantse Delta	Hydrometry and water management	03-12-2021
6) L. Janissen	Senior Advisor of Monitoring (Senior Adviseur Infomartievoorziening)	Waterschap Limburg	Environmental monitoring and information management	03-12-2021
7) M. Pauly	Advisor Space and Innovation (Adviseur Ruimte & Innovatie)	Gemeente Sittard-Geleen	Smart Cities, innovation and participation	13-12-2021
8) T. Deurloo	Senior Advisor of Water Management (Senior Adviseur Waterbeheer)	Waterschap Brabantse Delta	Hydrology and data science	14-12-2021

Annex B

Semi-structured interview guide

Topic 1: Background

- Q1: What is your professional and academic background?
- Q2: How long have you worked for your current employer?
- Q3: What is your exact role in the organization that you are working for?

Topic 2: Professional experiences with IoT

- Q4: Have you come across IoT applications in your current or previous work?
- Q5: How is IoT utilized in your line of work?

Topic 3: Opinions on IoT implementation

- Q6: What are in your opinion the key application point of IoT in climate adaptation and mitigation?
- Q7: What challenges have you come across in the implementation on IoT?
- Q8: Do you know how IoT is currently utilized in urban climate adaptation and mitigation in Limburg?
- Q9: In your opinion, what is the potential for the further implementation of IoT in urban Limburg?