AALBORG UNIVERSITY
COPENHAGEN

Semester: 4th Semester

Title: Using Internet of Things Platforms to Create Value in Copenhagen

Project Period: 21/9/2017 – 4/1/2018

Aalborg University Copenhagen
A.C. Meyers Vænge 15
2450 København SV

Semester Coordinator: Henning Olesen

Secretary: Maiken Keller

Semester Theme: Master Thesis

Supervisor(s): Morten Falch

Project group no.: 4BUS 4.25

Members
(do not write CPR.nr.):
Mikkel Sønderkær Mikkelsen

Abstract:

The Internet of Things (IoT) brings with it many opportunities, especially in relation to the area of smart cities. But due to the increasing complexity of technological solutions, the city of Copenhagen has many challenges to solve, to achieve sufficient value from IoT. An increasing trend to ease the implementation of IoT solutions is to adopt an IoT platform. Many highly capable IT vendors offer IoT platforms, but despite the seemingly optimal match between IoT platforms, and cities' needs, the adoption of such solutions is lacking. The research presented in this report is therefore aimed at understanding how an IoT platform provider's business model can be adjusted, to match the needs of Copenhagen.

To address this question, an analysis consisting of the following three elements is presented; a set of requirement specifications to clarify the needs of the city, a hype cycle and maturity model to forecast the potential of the IoT platforms, and finally the STOF-business model framework to understand how the IoT platforms can match the city's needs.

Key findings include a medium level of maturity, and guidelines for platform providers to match Copenhagen's needs through establishing an ecosystem around the IoT services, proving flexibility in both pricing, technologies and services, and attaining sector specific capabilities. Implementing a single IoT platform throughout the city of Copenhagen will not happen in the nearest future, but could be beneficial in many relations, if realized.

Pages: 98
Finished: 4/1/2018

Using Internet of Things Platforms to Create Value in Copenhagen

Mikkel Sønderkær Mikkelsen

Master Thesis

Innovative Communication Technologies and Entrepreneurship
Aalborg University Copenhagen

January 4th 2018

Image: Copenhagen Solutions Lab

Table of contents

1. Introduction

As the capabilities of information and communication technologies develop, new possibilities and application areas emerge, and technology becomes increasingly ubiquitous in our societies. When these capabilities are combined with decreasing hardware prices for devices such as sensors and actuators, the potential for developing innovative and connected solutions increase. By connecting such solutions in networks with other solutions, valuable data and information is created, making it possible to move from making opinion-based decisions to evidence-based decisions (Bosch & Olsson, 2017). This development is at the essence of the Internet of Things (IoT). The IoT term covers the action of connecting such sensor networks to the Internet, making it possible to interact with massive amounts of devices and the data created by them.

With application areas ranging from connected coffee machines to city infrastructure management, the possibilities of IoT is not limited to a specific sector. And as the number of connected devices on a global scale is expected to reach 20 billion by 2020, the conditions for IoT solutions improves (Gartner, 2017c). This also affects the global market for IoT solutions, which is expected to rise from $800 billion in 2017, to $1.4 trillion in 2021 (IDC, 2017). However, with the increase in capabilities, the systems become more complex, which presents challenges for both developers and users of the IoT solutions. Companies with experience in dealing with complex technologies, are therefore increasingly providing services, where the development and control of IoT solutions is made possible in a simple way. These services are combined on IoT platforms, and with technology giants such as Microsoft, Cisco, Amazon, IBM, and Google providing their own versions, the platforms could play a major role in the future of IoT.

An area of society that also faces radical evolution is the cities, where population sizes, density, and use of resources is increasing at a fast pace. This trend is estimated to continue in the future, and by 2050, 70% of the world's population is expected to live in cities (Aoun, 2013). These conditions create exceptional demands for the services and capabilities in all aspects of the city, and the technological evolution could be a key factor for meeting these demands. When applying technological solutions to city-related activities, and focusing on both efficiency and sustainability, the cities become better equipped for meeting future demands, or in other words, smarter (Giffinger, 2007). There are many application areas for smart city initiatives, including waste management, traffic congestion, energy, parking and lighting, but the common trend in all of them, is that they focus on providing value for the public society (Jin et al., 2014). IoT is a central element for creating smarter and better cities, and governments often play a major role in the adoption of IoT on both national and local levels (COWI, 2016)(World Bank Group, 2017).

The city of Copenhagen is no exception when it comes to the increasing demands caused by urbanization, and innovative solutions are needed to achieve ambitious goals of efficiency, environmental sustainability, and high living standards (Københavns Kommune, 2015). Some smart city initiatives are being implemented in Copenhagen, but mainly on an experimental stage. The value potential for adopting the technologies on a larger scale is substantial, making it relevant to improve the possibilities for realizing the value creation (ARUP & CEDI, 2016).

The trend in cities, based on urbanization, is that functions and operations are becoming more connected, creating a network of systems, where IoT can play an important role (UN, Ericsson & ITU, 2015). And with the increasing trend of IoT platforms provided by highly capable technology vendors, these two elements seem like a perfect match. but the adoption of an IoT platform in relation to city management in Copenhagen has yet to happen. The aim of this research is therefore to understand what the situation is, and what the possibilities are in the future, for creating value in Copenhagen through IoT platforms. The research will take the perspective of the platform providers, in order to assess the necessary business model aspects, which need to be adjusted. The research will be guided by a research question, which is defined in the following section.

1.1 Problem definition

There are many interesting elements of the technological development for both IoT and smart cities, and based on the initial research presented in the introduction above, the following research question has been formed:

How can an Internet of Things Platform provider's business model be adjusted to match the needs of the city of Copenhagen?

1.1.1 Delimitation

One of the main delimitations of this research comes naturally from the scope of focus; the technological elements will have an analytical and strategical approach, which makes very detailed technical considerations unnecessary for answering the research question. However, knowledge of the underlying technologies is essential for understanding the operations of the IoT Platforms, as well as analysing the potentials of the IoT solutions. A review of the state of the art within the technology is therefore included.

Some of the central challenges for IoT solutions are related to the lack of security, compromised privacy, and problems related to interoperability, based on the heterogeneity of standards and devices (Hussain, 2017). Such elements could also be highly relevant to research, with the purpose of clarifying best practices for e.g. IoT solutions in Copenhagen. But including these in this report could make the focus less clear, and would require additional resources. They will be mentioned briefly, but will not have a central role in the research.

Focusing on the IoT platform provider in the research question to some extend limits out the other stakeholders, included in the ecosystem surrounding the value creation in Copenhagen. This was done due to the large potential the platforms show, and to limit the scope to a manageable level.

Lastly, the focus on Copenhagen was made to create a specific case, instead of looking at the platforms and the IoT potential for smart cities on a global scale. Copenhagen is a well-developed city, that shows good conditions for IoT adoption, making it interesting to focus on in relation to this research.

The following section will briefly describe the contents of each chapter in this report, and mention some of the choices made regarding formatting.

1.2 Reading guide

After this introduction, which provides an overview of the research scope and the research question, the methods chapter will be presented. Here, the focus will be on the methodological approach and the design of the research.

The third chapter will provide the background information for the analysis to be based on, and will include a focus on the state of the art within the fields of IoT, IoT platforms, and smart cities.

After the foundation of knowledge has been established, the appropriate theoretical framework for addressing the research question can be developed. This will be presented in chapter four, and will include three overall approaches; requirement specifications, technology forecasting and business models.

Chapter five consists of a market overview, with the purpose of understanding the current situation regarding IoT platforms in Copenhagen. The market overview will also include the empirical data of this report, consisting of three expert interviews.

The main analysis, where the theoretical framework is applied to the gathered data, is presented in chapter six. The conclusion of this analysis will contain the main findings, which will be used to address the research question.

Chapter seven contains an evaluation of the findings, and a discussion of the research outcome, as well as some thoughts on potential next steps for the research. The purpose will be to assess the methodological and theoretical choices, and see how they have influenced the research.

The concluding part of the research is presented in chapter eight. This includes the main findings and the answer to the research question.

Chapters nine and ten contains a list of references and the appendix.

Throughout the report, the American Psychological Association (APA) style of referencing will be used. The interviews will be attached to the final delivery of the report in digital audio files, and has been labelled in the appendix, to make referencing of specific statements possible. Figures and other materials referred to as “author”, implies they are the original work of the author of this report.

2. Methodology

The purpose of this chapter is to clarify the theory of how the research was undertaken (Saunders, 2011). The design of the research will be described and illustrated, in order to argument for the selected design choices, and to clarify how the research was conducted. The following section will elaborate on the choices of contents in the individual chapters presented in the reading guide.

2.1 Research scope

The starting point of the report is found in the research question, which was formed in the previous chapter. This not only set the focus if the entire research, but also narrowed the scope, in order to keep the report on a manageable level. But to understand the fundamentals of the domain in focus, the subjects of smart cities, Internet of things, and IoT platforms has to be clarified. These three areas are developing fast, and it is therefore interesting to review the cutting edge technologies used in the fields. By focusing on IoT platforms in relation to a city, the research takes a meso-perspective, as opposed to a micro or macro perspective. This also means that the level of detail in the technological research was kept at a level where the fundamentals were clear, and some of the most important technicalities were accounted for, but a very detailed view was not necessary, as mentioned in the delimitation of the introduction.

Theoretical tools are needed to perform the analysis, and ultimately answer the research question. The combination of technology-related elements with a service development approach, and business related-elements with more of an analytical approach, was intended to be reflected in the theoretical framework. Therefore, requirement specifications, which are commonly found in relation to software development, were used to pinpoint the needs of the city. This theory was followed by a technology forecast, which included a review of the maturity level, in order to attain an understanding of the technological development in a strategic perspective. Lastly, a business model theory was used to research the possibilities an IoT platform has for creating value, by fulfilling the needs of the requirement specification, and at the same time considering the nature of the market and the technologies involved.

Before these tools were applied, it was necessary to understand the current market situation. This was a form of case-description, where the technologies and terms researched in the early stages of the report, were anchored to the specific focus areas of the research question. Here, the empirical data was presented, to have valid and original material for the analysis to be based on.

In the analysis, the theoretical tools were applied, and the hybrid approach of both technology- and business related elements was used to combine the view of the city in relation to smart city initiatives, with the business model ecosystem of the IoT platforms, as well as the technological possibilities and limitations of IoT in general. The outcome was therefore a set of recommendations for the platform providers, to attain a role in the smart city ecosystem, which generates value for the city. This outcome evaluated and discussed, before a final conclusion of the entire research, and an answer to the research question was presented.

2.2 Research approach

The approach of the research in this report revolves around the research question, which the entire contents are aimed at addressing. The purpose of the research was to identify a theory, which, based on the analysis of the data, was proposed as an answer to the research question. Forming the research this way, was based on a realization that company business models, city needs and technological development are highly dynamic fields, that does not necessarily follow a strict and predictable way of responding to their contexts. The combination of the fields can be done in various ways, which makes the solutions adaptable and allows for multiple explanations of the outcomes. These characteristics of the research fit very well with an inductive research approach, which starts with a research stage, then analyses data, and ends with a theory (Saunders, 2011).

In contrast, a deductive research approach starts with a hypothesis based on a theory, which is then tested and evaluated, in order to confirm or reject the initial hypothesis. If this research can be repeated with the same results, the findings are considered valid, and the answer can be generalized for situations with the given circumstances (Saunders, 2011). The highly structured and testable nature of the deductive approach makes it useful in scientific research, and especially in the fields of natural science. It can be a faster way of researching, as the experiment can be conducted once, and produce results that satisfy the hypothesis. But in relation to the research in this report, qualitative data was highly relevant, to understand the complex and dynamic contexts of the technologies and stakeholders. A faster, more controlled test would not fit these characteristics very well. The inductive research approach was therefore chosen, in order to answer the research question. The following section will address the data collection methods used in the research.

2.3 Data collection

Primary data, which was gathered by the author, consists of three interviews. Semi-structured interview guides were used, making the progression of questions flexible, and allowing the flow of the conversation to set the pace of the interview, rather than following a strict plan (Bjørner, 2015). Furthermore, the structure allowed follow-up questions to be added. This was done to let the interviewees expand on their statements, since it was considered that the interviewees had more knowledge of the subjects discussed than the interviewer, and a strict plan therefore might have limited the information attained. Having this type of open-minded approach is a characteristic of effective interviews in general, as it avoids limiting the interview to a pre-conceived outcome (Sommerville, 2010).

The interviewees were recruited based on their roles in their field of work. It was desired to address the topic of IoT platforms for smart city activities from both the city's- and the platform provider's perspective, as well as having an input from a neutral third party, who has experience working as a mediator between the two.

The qualitative data attained through the interviews will be presented in three ways:

1. A summary, or meaning condensation, in the market overview chapter (Bjørner, 2015).
2. Citations of statements relevant to the various topics in the analysis.
3. Full length recordings in audio files attached as digital appendices to the report.

Key-informant interviews, also known as in-depth interviews, were used as these are better at discussing complex situations, such as business models, as opposed to a higher number of short interviews (Bjørner, 2015). Using methods such as questionnaires or surveys was not chosen, as the qualitative approach fitted better with the purpose of the data, and as sufficient quantitative data was attainable through secondary research.

The secondary data, which constituted the majority of the data in this research, was based on literature reviews, as well as market research. Research produced by consultancy companies and market analytics organizations, played an important role in the data used for the analysis. However, some of the most relevant data in this field costs a substantial amount of money, so a requirement for the secondary data was that it either allowed public access, or was available through the resources of Aalborg University. This also applied to academic research papers.

2.4 Research design

Figure 1 illustrates the design of the research for this report. The clouds explain the purpose of the individual segments, and the squares define the contents. The vertical red arrow refers to the progression of the research, starting from the research question and motivation, and ending with an answer to this research question based on the findings.

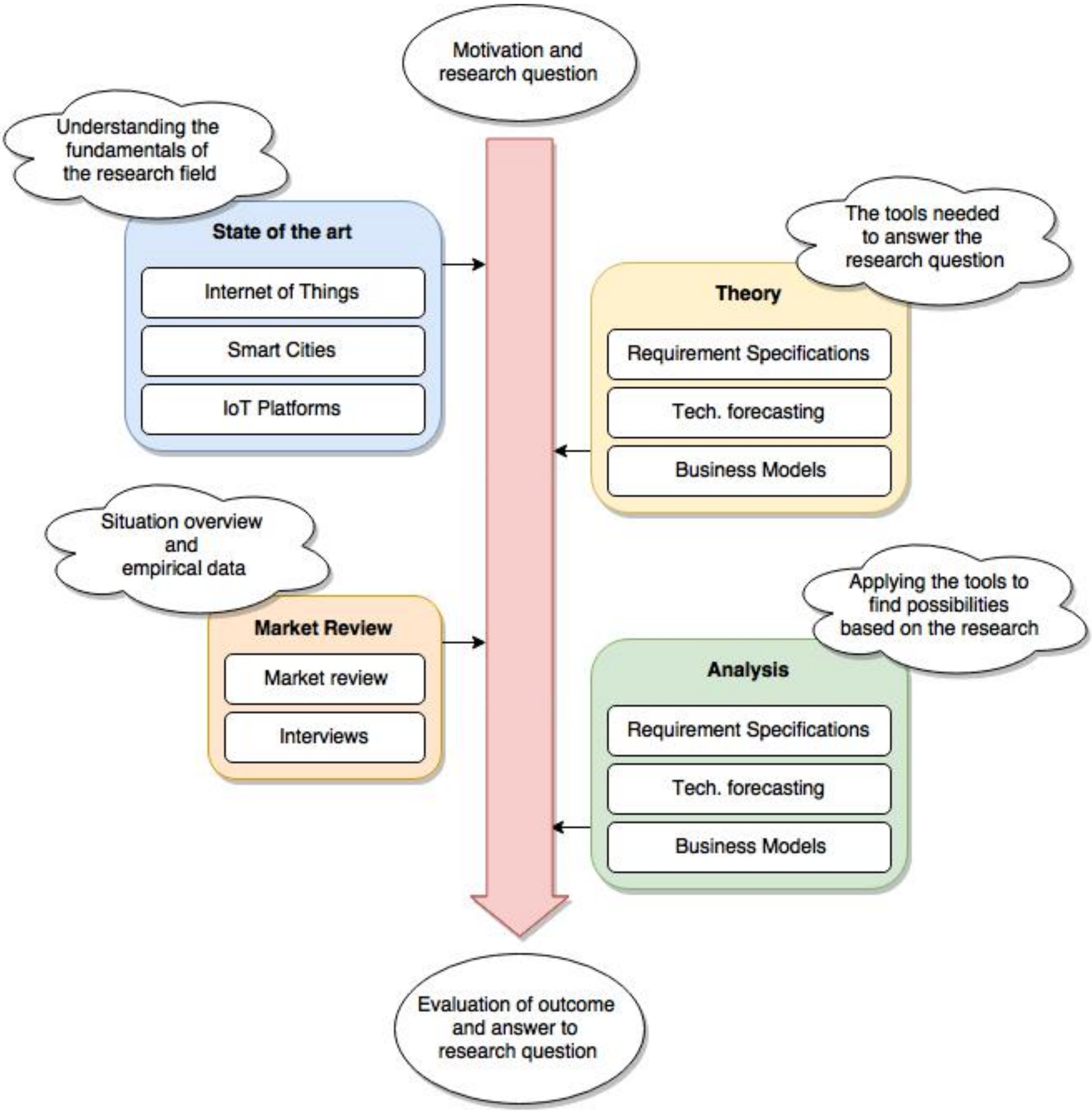


Figure 1 – The research design (Author)

Now that the research design has been clarified, the background information and state of the art overview, will be presented.

3. State of the art

This chapter focuses on the latest developments in the three main topics related to the research question, being IoT, smart cities, and IoT platforms. Due to this focus, the chapter is referred to as the state of the art. As mentioned, the aim is to create a solid foundation of knowledge, for the following research to be based on.

3.1 Internet of things

In the very first step of the research, the technical contents and workings of IoT will be reviewed. As the review progresses, focus will be on the term itself, the technological architecture, the main protocols and the common considerations for developing IoT solutions.

3.1.1 Definition and origin of Internet of things

The internet of things (IoT) is not a new term, but the meaning has evolved over the last decade. It can be looked at as an evolution of multiple machine-to-machine (M2M)-systems. The two terms are therefore not far from each other, but vary slightly in their scope. The philosophy behind M2M regarding insights from machines or things remains the same, but what could be considered isolated silos or horizontals of individual M2M-systems, are now interconnected and available to a larger amount of possibilities through the internet (Alam, Nielsen, & Prasad, 2013). The purpose of both systems is to act based on clear insights, rather than routines or instincts. And this is achieved by not only connecting the things to the internet, but also by analysing these data, combining them with other datasets, and by using these insights in the decision-making processes.

In its essence, internet of things deals with connected devices and sensors, which transmits information over the network of networks, which is the internet. A more factually correct formulation of the term could therefore be "*the internet relating to information of things*" as presented by Huang & Li (Huang & Li, 2010, P. 483). However, these are merely matters of wording, and what is essential is the actual elements of the technologies involved, and how they are used in practice.

One of the key technological advancements, which started much of the development around IoT was radio frequency identification (RFID). This technology provided the opportunity to implement an electronical circuit or a "tag" on things in a very cost-effective way, and thereby making it possible to receive information form things that would otherwise be hard to connect to an information system. These RFID tags consists of an antenna and a micro-chip containing the ID. Some RFIDs also have a battery, making it possible to transmit signals over greater distances (up to 30 meters). These are called active RFIDs, whereas the ones without a battery, only transmitting when affected by the signal from the receiver device, are called passive RFIDs (Yan et al, 2008). Figure 2 illustrates a simple

IoT system using RFID tags. In this example, and with the use of RFID in general, the tags are not limited to include only an ID number. Sensors can be included in the physical objects, and combined with the RFID technology, to transmit both an ID and e.g. a temperature measurement. With the development of new technologies regarding both communication, sensors and actuators, the possibilities of IoT solutions are increasing drastically.

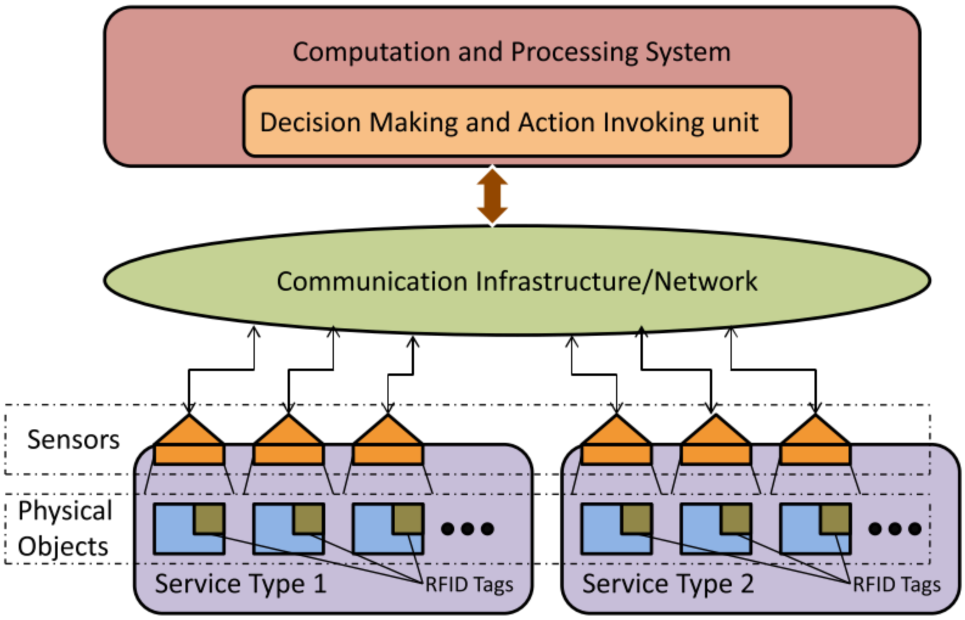


Figure 2 – A simple IoT system with two services based on RFID tags (Kahn et al, 2012)

Cloud-based technologies with capabilities such as accessing computing power, data storage, data analytics, scalability and much more, makes the IoT systems increasingly advanced, and further improves the possibilities of IoT networks. In a sense, these possibilities also played a part in creating of the idea behind IoT. However, accessing the cloud requires a certain amount of bandwidth and has to rely on a stable connection to function. Some IoT systems that are either very time sensitive, located in areas with poor internet coverage, or are limited in other way, can have problems with reaching the full potential of the cloud. Therefore, it can be necessary to move some of the capabilities of the system closer to the connected things, also referred to as end nodes. This solution is what Fog Computing consists of. The access points to the network requires more capabilities in such networks, but makes advanced IoT solutions possible, when cloud solutions fall short. In vehicle-to-vehicle communication for example, which can be considered a part of an IoT network, the latency for connecting to a cloud server might be too great. If the vehicles instead only had to connect to a network edge device capable of processing the connection and responding accordingly, the quality of the system could improve (Chiang & Zhang, 2016).

3.1.2 Network architecture

IoT relies on an architecture stack with quite a lot of capabilities in the lowest layer, which is usually referred to as the physical layer. Based on a review of literature related to IoT architecture stacks, also known as reference models, the figure 3 was created, and will be elaborated on in the following section.

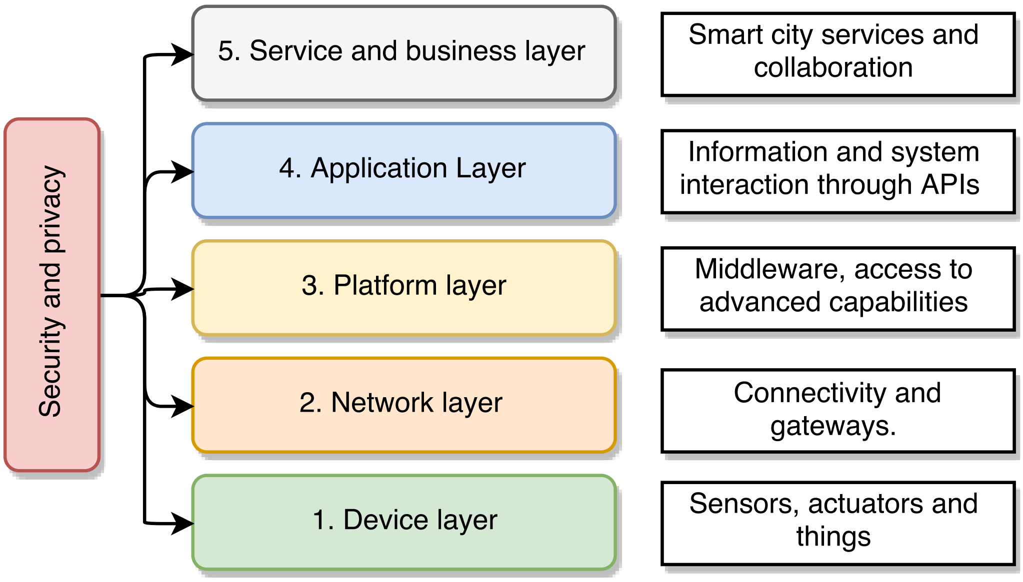


Figure 3 – the IoT architecture stack. Adopted from (Yaqoob et al, 2017)(Minoli et al, 2017)(Tisljareo, 2016)(Vermesan et al, 2015)(Khan et al, 2012)(Wang et al, 2011).

The main aspect of the stack is illustrated in the numbered layers, with examples of contents and functionality in the accompanying white boxes on the right. The individual layers of the architecture stack will now be presented.

1. **Device layer**

Some architecture stacks refer to this layer as the physical-, sensor-, or perception layer, but regardless of the name, the layer covers the end nodes in charge of the data acquisition, or in other words; the things. Many of the challenges related to IoT are a result of the heterogeneity of the things, as the interconnection between the upper layers and a multitude of sensors, actuators, some wired and other wireless, is very challenging.

2. **Network layer**

Communication protocols and their characteristics are the main contents of this layer in the stack. Some models refer to this layer as the gateway layer, the fog layer or the data aggregation layer. What is common for all, is the that it includes the connectivity to the last edge of the stack. The capabilities and purpose of the things connected in the device layer, has a large impact on the network layer. If for example the things have very limited data handling capabilities, the gateways might have to do some of the processing, or the communication protocol will have to be light weight and constrained. These protocols will be elaborated later in this chapter.

3. **Platform layer**

Also frequently referred to as the middleware layer, this is where the processing, storage, and abstraction of data is performed. The system management of the solution “back end” will also be performed in this layer, as this is where the data arrives before it is transmitted towards the relevant applications. In relation to IoT platforms currently offered on the market, big data analytics, machine learning and other data related services will be implemented in this layer as well. Often these services are parts of the platform provider’s portfolio of services, but this will be described in detail later in the report. Having a platform hub through which access to analytics capabilities is possible, is considered a centralised platform architecture, whereas systems in which these capabilities are more distributed, uses a decentralised platform architecture (Yaqoob et al, 2017).

4. **Application layer**

As described, the outcome of the data handling will be presented in applications for the various purposes of the individual IoT solutions. Here, the information transmitted to the platforms can be used to report on the state of the things involved in the solutions, and the front end of the applications can have features making it possible to control the things as well. For the end users, who are granted administrative controls, this will also be where the more operational management of the solutions can be performed, however, the developers will need access to lower layers as well.

5. **Service and business layer**

In the introduction to this chapter, it was stated that the information captured by the IoT solutions does not provide much value, without being implemented in business decisions. Therefore, this last layer is focused on how the data and information transmitted, analysed and evaluated by all other layers, can be used to create new value and business models. Some architecture stacks also refer to this layer as the collaboration layer, since the interconnection between multiple IoT systems can be used to create additional insights and value. An example hereof could be a smart city system, which interconnects with the systems used in other cities, to share insights, and collaborate on becoming smarter cities.

The security and privacy needs to be an integral part throughout the architecture stack, and many of the IoT solutions on the market, and IoT platforms in particular, focus greatly on these elements. However, many IoT solutions suffer from vulnerabilities in this area, making it an important area of development.

The content of the architecture stack is up to the solution developers to decide, and should reflect the attributes of the solution. The architecture can also use different network topologies, based on these attributes. If for example a vehicle-to-vehicle solution is being developed, a point-to-point topology could be relevant. Had the solution been a waste management system, where the need for communication between the connected devices did not exist, a star topology might be more optimal (Yaqoob et al, 2017). On a very fundamental scale, connecting the things to the internet starts with choosing technologies that support the adequate communication protocols. The following segments will expand on some of these protocols.

3.1.3 Local area communication protocols

Many different communication technologies exist, and serve different purposes. Once again, the heterogeneity challenge of IoT solutions is obvious, as the interoperability between these diverse protocols is challenging. Many of the protocols for device connectivity has been a part of the evolution of IoT, as mentioned earlier with RFID. Other examples hereof are the Near Field Communication (NFC), Bluetooth and Bluetooth Low Energy (BLE), Zigbee and of course WiFi. Table 1 expands on these communication protocols, and specifies their frequency, data rate, latency and range. These characteristics are chosen, as they provide an overview of the difference between the protocols, and because they can be crucial for the selection of one protocol over another. Other characteristics (e.g. power requirements, scalability etc.) are left out to keep the complexity of the table at an appropriate level. The same reason applies to the number of protocols covered. These have been chosen based on their large role in relation to IoT for smart cities.

Local area networks

Protocol	Frequency	Data rate	Latency	Range
RFID	136 KHz 13.56MHz 865-868 MHz 2.4 GHz	424 kbps	N/A[1]	50 cm 50 cm 30 m 1.5 m
NFC	13.56 MHz	100-420 kbps	N/A[1]	10 cm
ZigBee	2.4 GHz 900 MHz	250 kbps 20 kbps	5 ms	10-100 m
WiFi	2.4 and 5 GHz	600 Mbps (max)	28 ms	100 m
BLE	2.4 GHz	1 Mbps	6 ms	> 100 m

Table 1 – Common local area network protocols (Dhillon et al, 2017)(Li et al, 2015)(Designspark, 2015)(Stoltze, 2016)(Sigfox, 2017)(Dueholm, 2017)

[1] Latency for both RFID and NFC is so small that it is not a factor (Kitsos & Zhang, 2008).

3.1.4 Wide area communication protocols

When the data transmission needs to cover a longer range, or connectivity beyond the local area is needed, either the protocols used in the devices needs to be substituted, or a network access point needs to translate the transmission into a more suitable protocol, and pass it along in the network.

Much like local area networks, wide area networks have seen a lot of evolution in relation to both number of new technologies and their capabilities. And these protocols truly advance the capabilities of IoT solutions, as they potentially cover entire cities or countries, making it possible for vast amounts of devices to become part of the IoT networks. On this scale, the financial requirements for implementation of a technology is far greater than on the local scale. The adoption of protocols can therefore be subject of political debates and market conditions. However, low power wide area networks, also referred to as IoT- or sensor networks, are evolving in many countries. In Denmark, the incumbent on the Danish telecom market, TDC, is developing a proprietary narrow band (NB) IoT protocol in order to provide a wide area network for IoT (Dueholm, 2016). But other technologies are also being implemented, like Sigfox by IoT Denmark (Sigfox, 2017).

Table 2 illustrates some of the common wide area network protocols used in IoT systems, using the same parameters as in table 1.

Wide area networks

Protocol	Frequency	Data rate	Latency	Range
LoRa	Various	0.3-50 Kbps	low	2.5 Km (cities) 15 Km (Suburbs)
NB-IoT	In LTE spectrum	< 1 Mbps	100 ms	< 11 Km
2G **3G** **4G/LTE**	900 & 1800 MHz 2100 MHz 800, 1800 & 2600 MHz	100-400 Kbps 0.5-5 Mbps 1-50 Mbps	300-1000 ms 100-500 ms < 100 ms	< 35 Km 5 Km 5 Km
Sigfox	868 MHz	<100 bps	6 s	40 Km

Table 2 – Common wide area network protocols (Dhillon et al, 2017)(Li et al, 2015)(Designspark, 2015)(Stoltze, 2016)(Sigfox, 2017)(Dueholm, 2016)

Similar to the protocol choice for network communication, the development of the rest of the IoT solution is full of alternative protocols to select between, depending on the requirements of the specific solution.

3.1.5 Developing IoT solutions

The basic philosophy behind the Internet also applies to IoT solutions, meaning web objects need to be represented, identified and transported. These functions are commonly achieved using HTML, URI, and HTTP, however, when it comes to IoT networks, the capabilities in terms of processing power, power consumption, and more, results in limitations for these protocols. An example hereof is the XML protocol. XML is used to put structure on web content, by organizing data in text based categories. This makes it easily accessible for developers, as well as widely accepted in web services due to the simple nature of the protocol. However, the text based nature takes up quite a lot more space compared to binary formats of communication. The Efficient XML Interchange (EXI) protocol is addressing this issue, by encoding XML messages into a compact, binary form. The standard is developed in a W3C working group (W3C, 2014).

Figure 4 illustrates some of the common protocols, which are not constrained by the limited capabilities of simple end devices in an IoT system, as well as alternatives that are developed with the capabilities of IoT devices in mind.

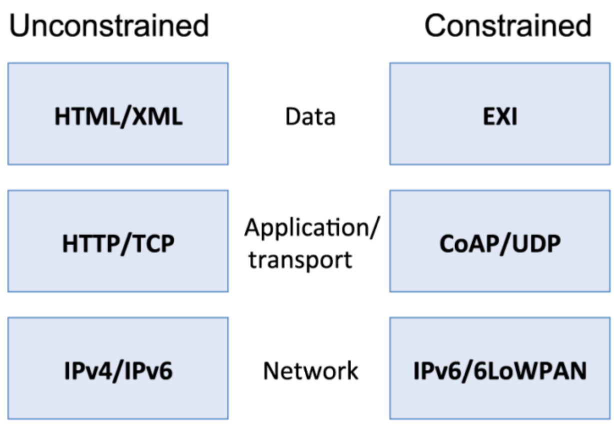


Figure 4 - Unconstrained and constrained protocols (Zanella et al, 2014 p. 26)

COAP uses much smaller packets than HTTP, but is otherwise very similar in relation to functionality. Another very popular alternative to HTTP is the lightweight messaging protocol MQTT. The difference between CoAP and MQTT is that MQTT uses a publish/subscribe system, making it easier for many devices to connect to multiple different services, rather than having to communicate one-to-one, as is the case with HTTP and CoAP (MQTT, 2014).

The IPv6 deals with the scarcity of addresses in IPv4, by adding to the number of available addresses. However, not all connected devices has the capabilities of understanding and communicating with the newer protocol, and so a form of translation has to be implemented in the system if this is the case.

Another noteworthy protocol related to IoT solutions is WebSocket. Here, instead of communication back and forth between a client and a server using e.g. HTTP, with a large meta-data header, a WebSockets connection is established, and maintained. This makes it possible to communicate continuously with a very small header around the actual data in the message, improving speed and data usage (Websocket, 2017).

Now that some of the fundamental technologies behind IoT has been researched, a number of challenges can be identified. First, the matter of heterogeneity, which has been mentioned a couple of times previously, is very significant. Many emerging protocols with limited consensus about which one to use, creates problems when systems scale up, and has to connect with other network elements that speaks an unknown language. This leads to the problem of interoperability between IoT systems, but also internally between elements of the same system. Furthermore, much of the value regarding IoT comes from the large number of connected devices, and the insights from the data provided by these. The systems therefore often rely on scale, which sets strict requirements for e.g. the amount of data each message can include, the power consumption, and of course the financial scaling as well. Lastly, IoT poses many obvious threats of personal privacy related to elements such as surveillance and data which potentially could be personal. Furthermore, the insights gathered form the distributed things create the potential for misuse and added power to the wrong people if the data is not secured properly.

As mentioned in the introduction, a trend in relation to the development of IoT solutions is that large companies and software vendors provide platforms, on which the solutions can function. The second section of the state of the art chapter will review the contents of these services, and focus on three existing platforms.

3.2 IoT Platforms

The need for integrated solutions to operate across multiple functionality- and service areas is rising, as the adoption of IoT increases (Vermesan et al, 2015). A large number of platforms are emerging, many of which aspire to become the “platform of platforms”, or what Google was to the search engine. Platforms vary in technological focus and capabilities, as well as the amount of services included in the solutions. Some are completely open source, others intended to be used only in specific sectors. What binds them all together is their core functionalities. The platforms are linking the sensors to analytical endpoints, and thereby improving the business outcomes. In other words, they largely rely on middleware functionality, making it possible for the sensing devices to focus their energy on sensing and transmitting the data, leaving the more demanding elements to the platform. The philosophy behind the middleware services is to use a Service Oriented Architecture (SOA), where the capabilities of the different web elements are provided as services, attainable though the higher layers of the network stack. The SOA is combined with cyber infrastructure (data management, mining etc.), making it possible to utilize vast amounts of functionalities, without having to deal with the complex elements of their inner workings (Tweneboah-Koduah, 2015). Furthermore, the platforms also cater for many, heterogeneous sensors to connect to the platform without knowledge of or compatibility with the language of the underlying services. In a scenario where a temperature sensor is used to determine the amount of water a plant needs to be given, the watering system could be coded in Java or C++. Instead of having to program the sensor in the same language, a simple XML message (or the constrained equivalent) could be transmitted to the IoT platform, which then activates the watering system.

Figure 5 illustrates the positioning of IoT platforms, in relation to the IoT solutions, and some of the main objectives for the services.

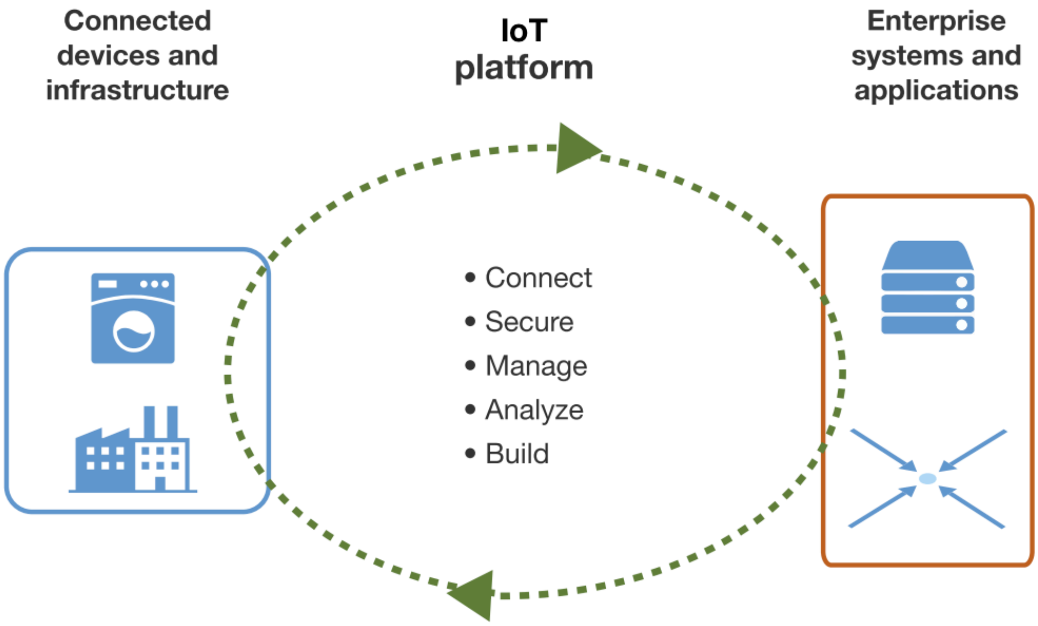


Figure 5 – The position of IoT platforms in relation to IoT solutions (Forrester, 2016)

The target group of each platform varies. Some are focused on specific industries, based on their additional service portfolios, which can be used to enhance the IoT services. The platforms are often aimed at solution developers, in the sense that the platforms provide the tools and capabilities, which a developer needs for structuring together a solution. The high level of platforms, and their varying characteristics, can make it hard to attain an overview of the functionalities included on the platforms. IDC describes some of the key features, which IoT platforms are focused at, as follows (MacGillivray, 2016):

- **Device management**

At the heart of the IoT services are the devices at the edge of the network. The data provided from these, and the control of them needs to be configured, certified, provisioned and maintained in order for the system to function.

- **Connectivity management**

IoT platforms has quite a challenge to deal with in terms of connectivity managing, and needs to be prepared to connect with a multitude of different protocols, devices and services. This challenge also means that there is a need in the market for solving problems related to connectivity, which is why IoT platform providers see a market for doing this in an efficient way. The level of complexity related to connectivity increases when the IoT services span over a larger geographical area, and even crossing country boarders. A common problem related to this is the management of the SIM-cards in the endpoints. IoT solutions providers should therefore cater for these challenges, and provide a simple one-point solution for connectivity management.

- **Application management**

Similar to the challenges regarding connectivity, the application development aspects of IoT solutions deals with the high level of heterogeneity, but also needs to make sense of the information contained in the data messages, rather than simply receiving them correctly. The management of the applications in both the development and functional stages therefore needs to focus on the collection, management and interpretation of data.

- **Dashboard and reporting**

When IoT solutions has been implemented using a platform, the users will most likely access the solution though a form of dashboard. This dashboard needs to include all relevant information for the given solution, as well as the possibility to export data for management-oriented summaries. A key feature of this information presentation is to normalize the data, creating an overview of the complex and comprehensive information.

- **Analytics**

The analytical capabilities of the IoT platforms needs to be at a reasonable level, in order for valuable insights to be created from the solutions on the platform. However, a large potential is present in the cognitive and complex analytics, which are increasingly accessible. Therefore, the IoT platforms needs to be capable of connecting to these services, and incorporate their analytics into the system.

To see how these functionality features are included in IoT platforms on the market, a review of three IoT platforms will be presented next. Many IoT platforms are relevant to focus on, but three have been selected to limit the scope of the review to a manageable level. Based on a market analysis produced by Forrester Research, the IoT platforms of Microsoft, Amazon Web Services and Cisco have the largest market presence on a global scale (Forrester, 2016). Since information regarding market shares in Denmark and Copenhagen are not available, the global market share is used to select the three platforms in focus.

3.2.1 Microsoft Azure IoT Suite

Microsoft provides a range of cloud-based solutions under the Azure name, and one of these solutions is the IoT Suite. The suite has many purposes, with preconfigured remote monitoring-, predictive maintenance- and connected factory solutions being a few. The combination of components in the suite depends on the needs of the specific IoT solutions, but a main aspect of the suite is the Azure IoT Hub (Microsoft, 2017a). In this hub, the focus is on bidirectional communication between the devices connected and the cloud (Microsoft, 2017b).

The hub relies on Service Assisted Communication, which focuses on creating a secure communication between the control system and the devices, by establishing strict requirements for which messages and requests to send, and where to send them. The foundation of service assisted communication is to view IoT devices as having a fundamentally different purposes on the internet than common devices such as serves, PCs, tablets or phones. The IoT devices needs stricter rules, which to some extend limits the capabilities of the communication, compared to the common devices, but benefits the security (Vasters, 2014).

The hub also includes device twins, which makes it possible to store metadata about individual devices, and send messages to these while they are offline, and presenting them when the device appears online again. The hub also contains per-device authentication, a rules system for routing device-to-cloud messages, operation logs for device connectivity, device libraries and supports IoT protocols such as MQTT, AMQP and of course HTTP.

In addition to the hub, the IoT Suite separates the functionality in three categories, which will be described next (Microsoft, 2017a). Figure 6 illustrates the solution architecture of the IoT Suite.

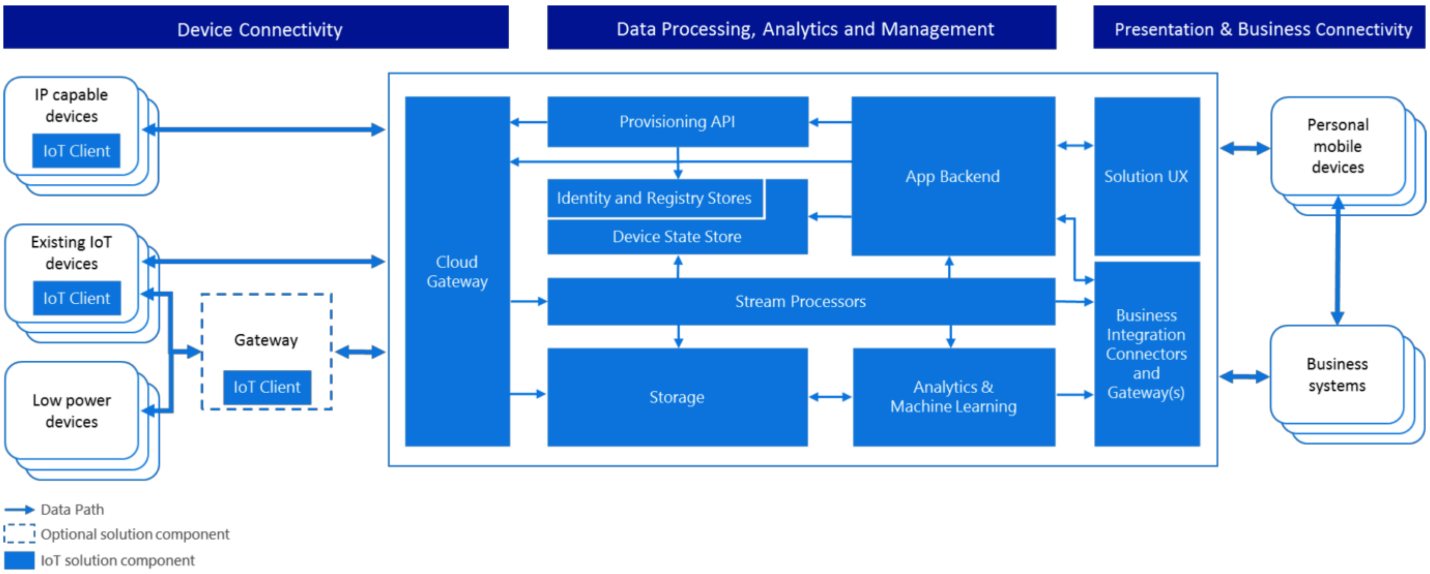


Figure 6 - Microsoft Azure IoT solution architecture (Microsoft, 2016).

1. **Device connectivity**

As mentioned, the communication is bidirectional, making it possible to not only retrieve information from e.g. a sensor, but also to send messages from the cloud back-end to the devices. This makes it possible to interact with the connected devices, and opens a vast amount of opportunities for control and agility of the solutions. A software development kit (SDK) is provided from Microsoft for both devices and the IoT Hub, making it possible to take full advantage of the capabilities of the platform.

2. **Data processing and analytics**

This is where the value of the data transmitted from the devices is established, as the back-end solution in the cloud analyses the data messages based on the chosen set of rules. Microsoft also provides a number of services, which can be applied in the back end for machine learning, data processing and analytics.

3. **Presentation and business connectivity**

When the IoT platform is used for the IoT solutions, the information can be accessed through dashboards or reports, stating the current situation as well as historic data. Furthermore, the IoT suite also allows for business connectivity and supports integration of the data into existing applications. The platform invites application developers to partner with Microsoft, and thereby provide functionalities on the platform from external developers.

It can be concluded that the Microsoft Azure IoT Suite is a wide-ranging IoT platform, with all necessary elements for solution development, from SDKs to data analytics. One issue with the platform is that could-based services only are supported in public-clouds, which could lead to some regulatory issues, regarding the storage of potentially personal data within smart city related solutions (Forrester, 2016). Furthermore, Microsoft has a history of pursuing their own standards, which could be problematic in a technological field that is highly dependent on interoperability.

3.2.2 Amazon Web Services IoT Platform

The Amazon Web Services (AWS) IoT Platform is one of the latest additions to AWS's impressive web service offerings. According to research conducted by Synergy Group, AWS is by far the leader on the global cloud market, with 34% of the market share in mid 2017, compared to 11% for Microsoft's Azure services (Synergy Research, 2017). Figure 7 below illustrates the main components of the AWS IoT platform solution.

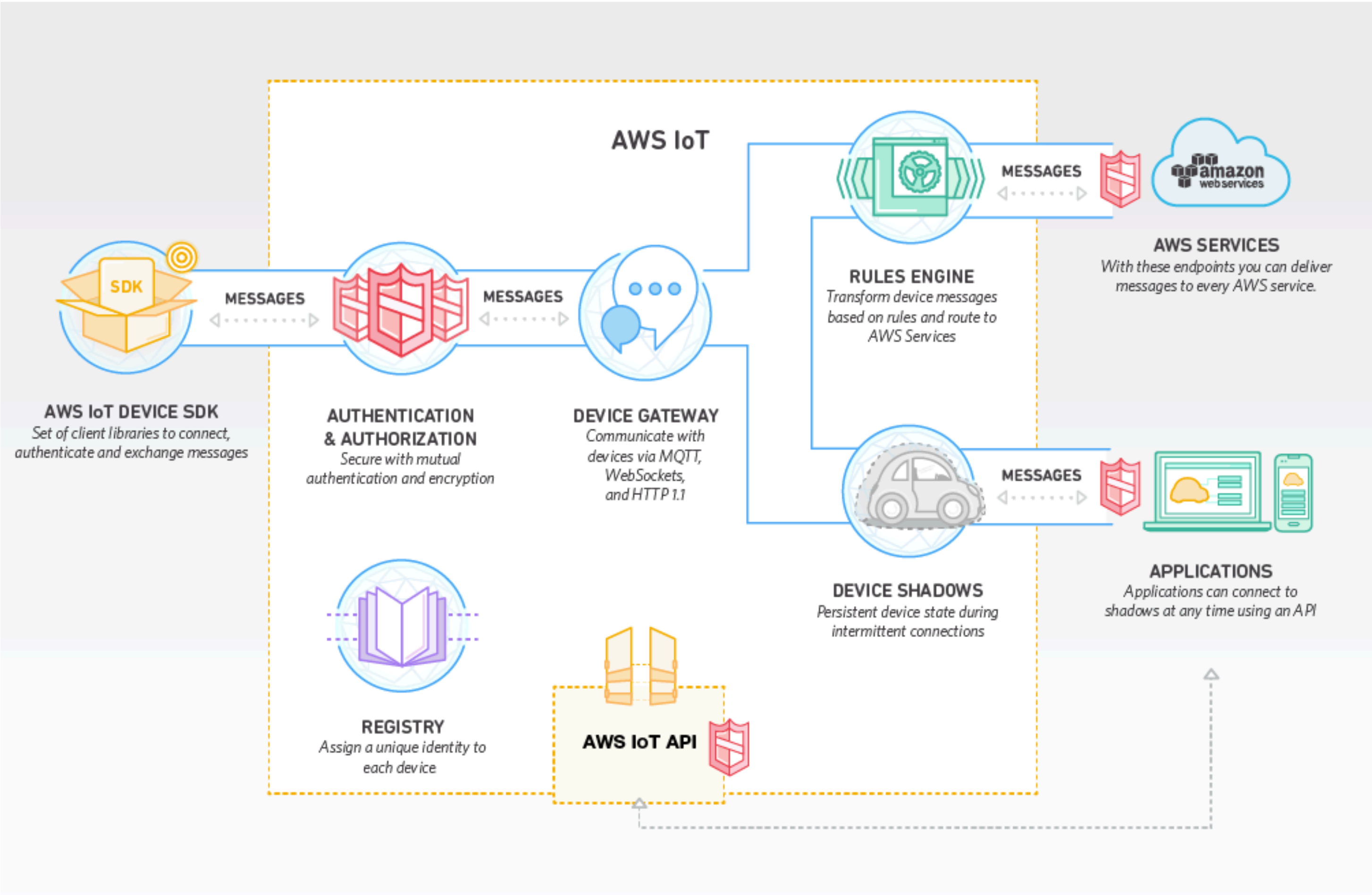


Figure 7 - AWS IoT platform solution overview (AWS, 2017a)

The functionality of the IoT platform includes many of the same elements as the Microsoft Azure IoT Suite (AWS, 2017a):

1. **Device connectivity**

A SDK is provided by AWS to support developers in realizing their IoT applications. The SDK supports multiple communication protocols (MQTT, HTTP and WebSocket) and programming languages (C, JavaScript and Arduino), but is only meant as a helpful service. Alternative SDKs can also be used to develop the devices, which are going to be connected to the IoT platform.

The Device Gateway is where the IoT devices connect to the platform, and allows to communicate via a publication/subscription model, meaning the sender (called publisher) pushes a message to a defined topic instead of addressing for a specific recipient. A component in the network who needs to receive the message from the IoT device simply need to subscribe to the given topic (e.g. temperature measurements), and will then automatically receive all messages pushed to that topic, improving the performance and scalability of the network (AWS, 2017b). Once again, the network protocols MQTT, HTTP and WebSocket are supported. It is possible to use multiple types of authentication based on the protocol used for the connection. AWS has their own authentication method called SigV4, but other methods and certificates are also supported, and can be created, deployed and managed from the console or the API. In the registry, devices are described by giving them an identity and adding metadata about the capabilities of the device.

2. **Data processing, analytics, presentation, and business connectivity**

Like the device shadows of the Microsoft Azure IoT Suite, the AWS IoT platform can create a persistent virtual version of the connected devices, which remembers the last reported state of the device. This makes it possible to retrieve the last reported information form a device that is offline, and set a desired future state, which the device is to take when online again. The device SDK makes it easy to provide the devices with the functionality of taking updates according to their shadow. Furthermore, REST APIs are available in the platform, making it possible for applications to interact with the devices and their shadows.

The content of the messages sent to the AWS IoT platform can be evaluated, transformed and delivered to devices, cloud services or external application based on rules set in the rules engine. In the rules engine, which is controlled through a management console or through a SQL-like syntax, the IoT application can take action based on messages from one device, or the result of combined information from many devices. This is where a big part of the functionality in the IoT application lies, and when combining the rules engine with external services or applications, the possibilities and potentials of the IoT solutions are very big.

The AWS IoT platform has been given credit for the high scalability and the extensive functionalities available through additional service offerings (Gerber, 2017). But the platform has been rather complex for developers to work with in the past (Forrester, 2016). However, the SDKs and interfaces have been improved, to allow simpler IoT solutions to be developed with more ease (AWS, 2017a).

3.2.3 Cisco Jasper and Kinetic for Cities

Cisco acquired the connectivity management platform Jasper in March of 2016, and has provided IoT-related services on this platform since then (Forrester, 2016). The Cisco Jasper platform consists of a control centre, which makes it possible to manage the connected devices, and attain real-time insights in the data provided by them (Jasper, 2017).

In addition to the Jasper platform, Cisco also offers a platform aimed entirely at cities, called Cisco Kinetic for Cities. Formerly known as the "Smart+Connected Digital platform", Cisco Kinetic for Cities is described by the VP/GM of IoT at Cisco as a "*cloud-based platform that helps customers extract, compute and move data from connected things to IoT applications*" (Menon, 2017). The platform focuses on cross domain contextual control, or in other words, combining data and knowledge from different sensors related to different city departments (Cisco, 2017a). This has the potential of fulfilling the needs of the cities to a larger extend, by focusing on their way of working from the start, instead of providing the technology, and leaving the organizational and use of the platform to the cities. However, the platform also provides open APIs, as many of the other platform providers, making it possible for independent software vendors and existing city systems to connect with the Cisco Kinetic for Cities platform (Cisco, 2017b). The solution architecture of Cisco Kinetic for Cities is illustrated in figure 8.

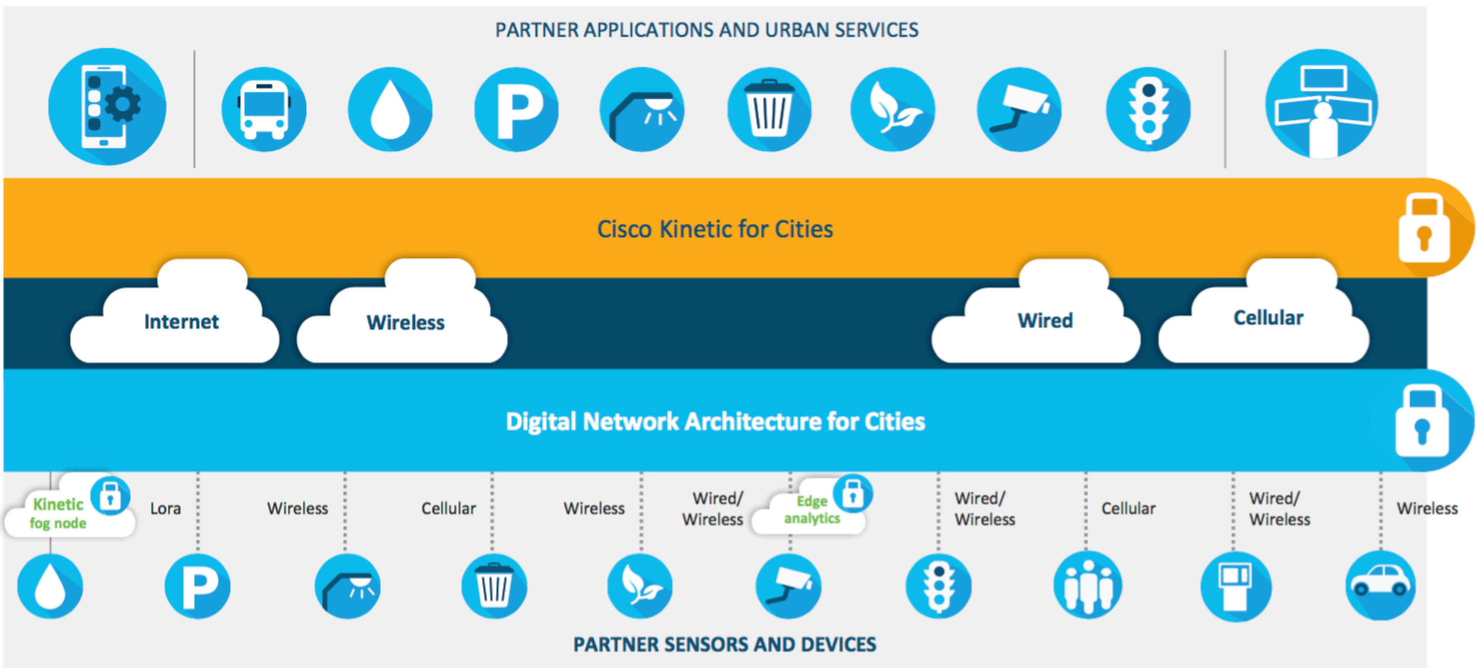


Figure 8 - Cisco Kinetic for Cities solution architecture (Cisco, 2017c)

The platform covers a wide range of functionality, and includes other modules from Cisco developed specifically for cities, such as a disaster dashboard module. In order to compare the Cisco Kinetic for Cities platform with the other platforms, the three-part division previously used will be applied:

1. **Device connectivity**

In this category, the Cisco Kinetic for Cities provides both a real-time device engine, which aggregates and normalizes sensor data, and a location engine, focused on mapping the connected devices for calculating distances and providing location-based tracking (Cisco, 2017a). Cisco also provides an extensive amount of hardware solutions in relation to information and communication technologies, which makes it possible for them to offer fog notes with advanced capabilities, and to perform analytics in the network edge if needed (Cisco, 2017c). SDKs and a developer community is also available for solutions developers (Cisco, 2017a)

2. **Data processing and analytics**

The data processing is performed by a time series data engine and an analytical engine. The time series data engine uses the stored data from the real-time device engine to identify patterns and trends, which the analytical engine can find further insights from. A service management system makes it possible to distribute the correct data among the services connected to the platform (Cisco 2017a). In general, the platform uses a XML-based language, which has been modified to the needs of smart city service applications. XML is used for simplicity and compatibility with other systems (Cisco 2017a).

3. **Presentation and business connectivity**

The platform is highly focused on creating an open ecosystem around the IoT solutions, and much of this comes from the capabilities of granting access through APIs and interconnecting with services such as city databases, systems and even other city platforms. A City API is among the key functionalities of the platform, as this makes it possible for the multitude of departments and users to interact with the platform. Like Microsoft's Azure IoT Suite, the Kinetic for Cities platform has also established partnerships with solutions providers, to create an ecosystem around the IoT solutions (Cisco, 2017c).

Access control to the platform is configurable in multiple ways, through multitenancy functionality, which makes it possible to segregate user types, and define different access levels (Cisco, 2017a). Lastly, the platform provides a city dashboard, which makes it possible to view and interact with all IoT solutions connected to the platform on one single dashboard. This dashboard is also available in a mobile application, suitable for city personnel using the solutions while moving around the city (Cisco, 2017c).

Examples of solution use cases on the Kinetic for Cities platform are lighting, parking, urban mobility, environment, safety and security, and waste management (Cisco, 2017a)

The research of the three IoT platforms makes it clear that a complex range of capabilities are needed for the platforms to function. Even though the three platforms have capabilities that are needed in all IoT solutions, they vary slightly from each other, making it possible to choose the best platform, based on the requirements of the individual solutions. In relation to creating value in Copenhagen, the Kinetic for Cities platform by Cisco is by far the most developed and advantageous, as the capabilities are specifically aimed at cities. The following chapter will look into the elements of smart cities, to clarify what the specific opportunities and barriers are for making cities better, and to understand how IoT can be useful in this regard.

3.3 Smart cities

The definition of a Smart City can vary to a large extend. A researcher, who has been frequently cited in relation to coining the phrase "Smart City", Rudolph Giffinger, argues a smart city relies on the following six characteristics (Giffinger, 2007):

- Smart Economy
- Smart people
- Smart governance
- Smart mobility
- Smart environment
- Smart living

In his smart city study of 2007, Giffinger establishes a method containing 31 factors, derived from these six characteristics (e.g. productivity under smart economy, and pollution under smart environment), and adds specific indicators, used to quantify the scores of individual cities.
He defines a smart city as "*a city well performing in a forward-looking way in these six characteristics, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens*" (Giffinger, 2007, p.11). Yet, 10 years later, the definition is still not concise amongst different publications. A comprehensive smart city literature review from 2014, which also focuses on Giffinger's research, presents a mismatch between the smart city definitions within the field of academia and the industry.

In academia, the argument stands that intellectual capital (e.g. citizens'-, companies'-, and cities' culture) is the main component of a smart city, whereas the industry appoints technology as being the main component (Dameri & Rosenthal-Sabroux, 2014). This statement also seems to apply when looking at Danish publications on smart cities, such as the one produced by the Ministry of Foreign Affairs in collaboration with the consultancy firms Arup and CEDI, which argues that the smart city concept represents "*technology-driven urban benefits and the products and services that deliver them*" (ARUP & CEDI, 2016, p. 6).

The focus on sustainable development also seems to be a major factor in many definitions of smart cities. Schneider electric, who deals with a wide variety of electronical solutions related to smart cities, defines a smart city as one that is "*efficient, liveable, and sustainable*" (Aoun, 2013, p. 4). The UN and the International Telecommunications Union (ITU) in collaboration with Ericsson takes this approach further, and combines the smart and sustainable aspects into one overall focus area, which includes many subdivisions of the society, much like the definition of Giffinger's characteristics. But the UN, ITU and Ericsson argues that "*In fact, what makes something "smart" is the integration of ICT based concepts such as big data, open data, Internet of things, as well as data accessibility and management, data security, mobile broadband, and ubiquitous sensor networks*" (UN, Ericsson & ITU, 2015, p. 4). Furthermore, they state that cities focusing on the incorporation of ICT has a greater chance of meeting the Sustainable Development Goals set by the UN, which could explain the reasoning for combining the focus on being smart and being sustainable.

Due to the technology-focused nature of the research in this report, the approach to the smart city subject will lean closest to that of the industry and ICT-based definitions, as a wider societal smart city focus covers too wide an area. A complete avoidance of city-aspects, which are not directly linked to technology, is of course not ideal, as a city that breaks down individual silos of its infrastructural elements such as electricity and traffic, and creates a more collaborative ecosystem, can become more efficient and thereby also smarter (Aoun, 2013).

The objective of including a focus on smart cities in this research is to understand the value of creating a smarter city, and to illustrate how well an IoT solution corresponds with these values. Therefore, the challenges of cities, and qualified guidelines for overcoming them, is important to understand.

3.3.1 Challenges for smart cities

In general, cities are facing many challenges, including increased populations, polarised economic growth, increased greenhouse-gas emissions and decreased budgets (Cisco, 2012). At the same time, technology is evolving dramatically, which creates a lot of possibilities, but also creates complications in relation to interoperability and uncertainty of investments. The technology can both open op the society, but also isolate certain areas by leaving them out of the digital loop, and brings with it large complications related to privacy and security. But the potential for smart cities is large in both developed and developing countries, however, the challenges can vary. For developing countries, who are focusing on establishing the fundamental elements of an infrastructure, the smart city elements can be thought into the process form the very beginning, creating a better foundation for future smart city initiatives. In more developed countries like

Denmark, the challenges lie in breaking down outdated and inefficient solutions and organisations, which requires the cities to challenge the status-quo. But with limited budgets and hesitation for making substantial financial investments, making drastic changes can be hard. Therefore, solid business cases, forecasting, and innovative business models, which indicates the positive potential of the smart city investments and the technology it is based on, is needed to convince decision makers. If the smart city investments are approved, the solutions still need a lot of work to provide optimal value for the city.

3.3.2 Becoming a smarter city

A tendency in reports on smart cities is to establish a number of recommendations, guidelines or success criteria for how to reach a higher level of smartness in a given city. When reviewing literature on smart cities, some focused on Denmark and others with an international perspective, the following topics frequently appears (ARUP & CEDI, 2016)(Cisco, 2012)(Aoun, 2013):

1. Establishing an initial smart city vision and communicating this clearly to stakeholders
2. Identifying the technological requirements
3. Developing the smart city initiatives
4. Focusing on collaboration throughout the process

The following section will expand on how the literature publications argue for each of the abovementioned topics, in order to establish an overview of the choices to make for cities, in order to become smarter.

1. **Establishing a smart city vision and communicating this clearly to stakeholders.**

This vision should be long term and avoid viewing city elements as individual silos, but rather focus on an inclusive and collaboration based structure. When choosing the main objectives of the vision, it is also recommended to combine a top-down approach focusing on city values from a governmental perspective, with a bottom-up perspective including the values and needs of the citizens (Aoun, 2013). This combined focus can possibly lead to complications with conflicting values, such as an economic benefit on the industry's side, and data privacy on the citizen's side, which is why establishing collaborations and communication between stakeholders from the very start is important (ARUP & CEDI, 2016).

When the vision is established, the benefits and underlying reasoning should be communicated, not only to improve the transparency of the plan, but also to spur the development of smart solutions, and to include as large a part of the stakeholders as possible in the vision (ARUP & CEDI, 2016). Many cities have financial goals to reach, where environmental goals do not seem optimal for measuring the progress (Cisco, 2012). However, this combination is necessary in order to fulfil more than just the financial goals. In the City of Copenhagen, this is done by forcing environmental- and climate requirements in the requirements for public investments such as in public tenders.

Especially by incorporating the usage of energy over a product or service's lifetime into the business cases and financial planning of initiatives, makes it possible for the most sustainable solutions to become attractive competitors to otherwise cheap but unsustainable alternatives (Københavns Kommune, 2016a).

2. Identifying the technological requirements

Tremendous amounts of technological solutions are available for a wide variety of cities' problems. Many technological solutions related to smart city initiatives heavily depend on the data which is being gathered, and much potential is seen in sharing data between different stakeholders. Therefore, an increasing focus on providing open data is a way of avoiding limited scaling of smart city projects (ARUP & CEDI, 2016). Here, the essential elements are to collect the raw data, and then use it in combination with data collected from other areas of the city, to attain more information and knowledge across multiple areas through integration. This is where the underlying ideas of the technologies comes to play, as management becomes much more advanced and efficient through the access to relevant data (Aoun, 2013). This should of course be done while adhering to requirements for security and privacy. The task of connecting all the solutions and systems in order to achieve a higher amount of value, while at the same time adhering to the requirements, is a complex challenge. Experts are therefore needed to establish and clarify the technological requirements (Cisco, 2012). Additionally, no matter the specific technological solutions, working on the clarity of regulations and common standards used, needs to be a priority, as this is an area where complications can arise, limiting the progress towards becoming a smarter city (ARUP & CEDI, 2016). Many of these elements fit very well with the potential from IoT solutions, and the IoT platforms in particular.

3. Developing the smart city initiatives

As a continuation of the technological choices described above, the integration of the individual smart city solutions is an important task. The above-mentioned city data is an essential aspect of this integration (Aoun, 2013). In Copenhagen, an Open Data platform has been developed by the city of Copenhagen, to reach these benefits (CPH Solutions Lab, 2017).

How to scale the smart city initiatives, should also be considered during the development phase, as many solutions suffer from "pilot-sickness", where a lack of funding for the expansion of the solution, limits the progress after the initial test phase (ARUP & CEDI, 2016). However, the responsibility of the large-scale development does not solely rely on the willingness of the governments to invest, since the funds often are limited. Therefore, the solution developers have to be innovative. New business models can be an alternative to a large investment, but this requires the willingness to change up the status quo, as mentioned earlier. Examples of alternative funding sources such as energy saving loans, can be used to start the smart solutions, and parts of the savings can then pay back the loans (Aoun, 2013).

The development phase should of course be guided by the contents of the city's vision, and once again include the perspectives from all stakeholders. One way of working towards this, is to utilize the user-centred design approach, thereby catering for actual needs and problems of the city (ARUP & CEDI, 2016).

4. Focusing on collaboration throughout the process

Collaboration frequently appears in relation to smart city topics, and this makes sense given the complex nature of both challenges, stakeholders and solutions. The effects of digitalization have led to the convergence of industries and technologies, increasing the need for collaboration between different entities, as tremendous potentials are seen in the sharing of skills and resources. Therefore, it is important to overcome barriers such as competition in the industry and political differences, and focus on a common city vision (Aoun, 2013).

The collaboration is not limited to stakeholders within the industry, or between local governments of a country. Collaboration between all entities is important in the development of smart city initiatives. As an example hereof is the Danish "four strand helix", which covers the public, private, academia and civil society (ARUP & CEDI, 2016). In Denmark there is a problem related to accessing the skills and research related to smart city solutions, and without the access, the value is not utilized. It is therefore though collaboration and sharing of knowledge, that the benefits of smart city development is reached (ARUP & CEDI, 2016).

A trend in relation to creating better conditions for collaboration on smart city development is to establish a community where focus is on the process of collaborative innovation, rather than the actual smart city solutions (Cisco, 2012)(Aoun, 2013). In such scenarios, the local governments and city administrators can be the facilitators of the communities, creating a meeting place for solution providers and developers, while maintaining a focus on the strategy and overall smart city vision (ARUP & CEDI, 2016). An additional benefit from joining forces in such communities, is to create awareness about the smart city agenda, and provide a more tangible way of stimulating the development, which could make the city a leader in smart development, and attract recognition as well as talent globally (ARUP & CEDI, 2016).

In Copenhagen, a smart city hub called Copenhagen Solutions Lab has been created with the purpose of establishing such a community around the development of technological solutions to the problems faced by the city (CPH Solutions Lab, 2017). This hub will be described in more detail later in the report. Copenhagen also has a set of guidelines, forming their vision for meeting the demands for the city in the future. This vision will also be described later.

The challenges for smart cities, and the four stages involved in becoming smart, fit very well with both the technological possibilities of IoT platforms, as well as the needs form Copenhagen. The state of the art research on smart cities can therefore be used to guide the analysis towards findings that can be beneficial for the city of Copenhagen. The following section will present a brief conclusion of the three elements research in this chapter.

3.4 Chapter conclusion

The research of the technological aspects behind the Internet of Things revealed a large potential for the value created by the solutions, but also a large amount of barriers related to their implementation. This is due to the early stage of development, which the technologies are in, creating insecurity in relation to technology choices, security measurements and the financial investments. A trend for improving the development of IoT solutions was found in the IoT platforms. These platforms are complex and contain extensive capabilities. The contents of platforms include a fundamental set of capabilities, but the individual platforms vary in relation to target users and sectors. The focus on city’s needs in the Kinetic for Cities platform by Cisco makes it the most ideal platform out of the tree reached. In the review of smart city characteristics, the challenges and guidelines provides a relevant input for the development of technological solutions in Copenhagen.

The chapter has created a foundation of knowledge in relation to the tree main elements of the research focus. This will be used to make the analysis and its findings as qualified and relevant as possible.

In the following chapter, the theoretical approach for the analysis will be created.

4. Theoretical framework

As mentioned in the methodological chapter, the fundamental idea for the theoretical framework is to combine elements related to technological development, with analytical elements for both technology and the business ecosystems they are involved in. In this relation, there can be a pitfall in creating a theoretical framework, which is too extensive, and creates more confusion than relevant findings. It is therefore important to select theories that are able to complement each other, and work towards the same goal of answering the research question. The first two theories selected deals with understanding the needs of the city in relation to the IoT platforms, and justifying the focus on the platforms as potential solution providers. This will be done through requirement specifications and technology forecasting. The last part of the theoretical framework will then use the requirement specification and the forecast to understand how an IoT platform provider can adjust its business model in the specific context of the city of Copenhagen.

4.1 Requirement specifications

The purpose of this theory is to analyse the requirements of the IoT platforms from a technological point of view. But it should stay on the meso-level, meaning the goal of the requirements is not to pave the way for a system design in particular, but rather a set of guidelines for the platform providers to increase the value creation for the city of Copenhagen. The outcome of the analysis in which the theory is implemented, should not be large and complex, but rather a concise overview of the specified requirements.

4.1.1 The process of specifying requirements

The process of specifying requirements for a technological solution is often involved in the early stages of development, when the user or customer of a desired solution, in dialogue with the developers, specify what the solution should be capable of doing. Therefore, many theories related to requirement specifications include a detailed focus on functionality. But they should also include some fundamental clarifications of the user needs, which is relevant in relation to this research. A rather general theoretical method for specifying requirements is presented by Sommerville I., and can be seen in figure 9.

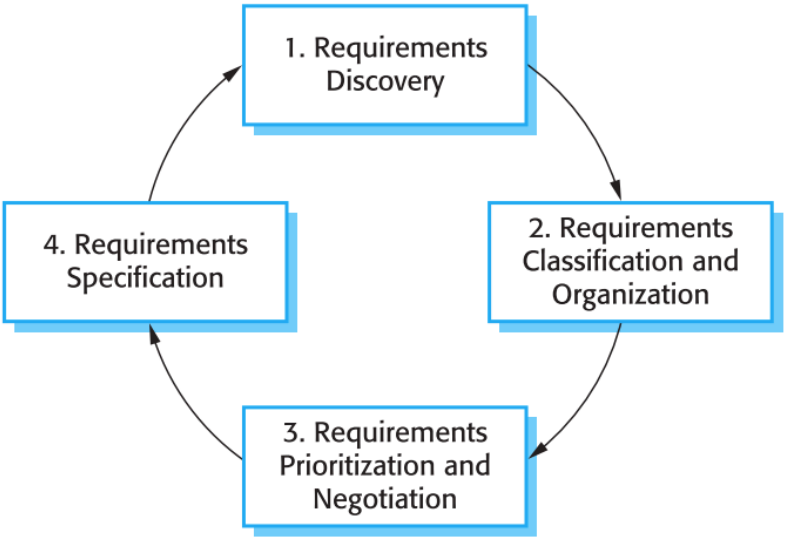


Figure 9 - Requirement specification process (Sommerville, 2010)

The contents of the four requirement specification process elements are as follows:

1. **Requirements discovery**

Information about the stakeholders and the processes involved in the platform should be researched. In relation to this report, an interview with the smart city incubator in the City of Copenhagen will form the foundation for the main stakeholder input on how value should be created in Copenhagen in relation to IoT. Therefore, this interview should form the foundation for the requirement discovery. Here, use cases and scenarios can be used to relate to the requirements in a more tangible way.

2. **Requirements classification and organization**

This part is closely related to the system architecture, where elements of the platform is divided into sub-systems, and the requirements related to these sub-systems are specified. The research of the IoT platforms performed in this previous chapter, functions as the foundation for these requirements.

3. **Requirements prioritization and negotiation.**

The stakeholders involved in the process of developing the system will often have different visions for what functionality and which features are the most important elements for the platform. This should be discussed, and the outcome should be a prioritisation of the requirements, which all stakeholders can agree on. Since the development of requirements is based on interviews, and not a common discussion with the involved stakeholders, the prioritization will not be emphasized in the analysis.

4. Requirements specification

The final requirement list can be both formal and informal, depending on the stage of the system or the purpose of the requirements. In this report, the outcome of the classification in the second stage will provide an overview of the requirements, and can therefore also serve the final purpose of presenting the specifications.

The following segments will describe the theories needed for going through the requirement specification process.

4.1.2 Scenarios and use-cases

Scenarios and use cases can be hard to distinguish, and often serves the same purpose (Sommerville, 2010). They deal with real-life examples of how interaction with the platform would play out, and specify the actions of both user and platform, in order to map the required processes. The scenarios should outline the interaction, and include what the expectations are for the outcome from both the user and platform perspective, what could go wrong, what is happening simultaneously and the state of the platform when the interaction ends (Sommerville, 2010). A use case diagram can be produced to illustrate the interaction with the platform, thereby producing an understanding of the requirements for the functionality. These can be made in varying levels of detail, spanning from a simple use case diagram, to more advanced UML-based class diagrams (Astestiano & Reggio, 2002).

4.1.3 Functional requirements

These requirements focus on what the platform should be capable of doing, and does not include how these requirements are met (Boyle & MacArthur, 2013). They are looking at the platform at a general level, and specify the very fundamental capabilities it should cover. An example of functional requirements for a specific IoT solution, such as a network of air quality sensors, could be:

- The system must:
  - Provide an interface for city management officials
  - Provide categorized data for citizens to access
  - Store historical data
  - Emit alerts when air quality is poor.

Functional requirements should strive for completeness, meaning all user or customer goals for the platform should be covered. There should also be as little ambiguity in the formulations of the requirements as possible. However, these goals can be very hard to reach when dealing with large, complex systems or solutions (Sommerville, 2010).

After the functional requirements have been established, a more general approach can be used to specify the requirements, which the following section will clarify.

4.1.4 Non-functional requirements

Often also referred to as quality requirements or quality of service (QoS) requirements, the non-functional requirements deal with the elements that are not directly related to the services of the platform (Sommerville, 2010).

They usually consider more than one function or even the system or solution as a whole, and therefore can be harder to measure and analyse (Nuseibeh & Easterbrook, 2000). The general focus in the requirements means they can be partially fulfilled, in contrast to the functional requirements, where there is a definitive answer to their ability of living up to the requirements (Berander & Andrews, 2005). The non-functional requirements can spawn from many areas, but the three most common areas are as follows (Sommerville, 2010):

1. **Product requirements**

In relation to software development, the product requirements consider the behaviour of the software. for IoT solutions and platforms, software will play a major role, however, the product requirements could also cover elements such as hardware and network architecture.
Examples of product requirements are efficiency (performance and space), scalability, availability, usability, dependability and security.

2. **Organizational requirements**

The platform developers, as well as users, will have a set of policies in place for how they conduct their business. These policies will require certain elements of the developed system, which is what the organizational requirements consists of. Organizational requirements are often related to environmental-, operational- and developmental policies.

3. **External requirements**

As the name implies, these requirements deal with elements that are not included in the development through the customers, users or developers. Many external requirements are potentially affecting the platforms, but not all has to be included. Examples of external requirements are regulatory, ethical and legislative (accounting and safety/security).

Based on the theoretical frameworks presented, the requirement specification in the analysis will use scenarios and use cases to form requirements that are both functional and non-functional. The following part of the chapter will present the theoretical considerations related to the technology forecast.

4.2 Technology forecasting

Investments in new technologies has a lot of risks, especially if the technology does not live up to the expectations, and the return on investment fails. Therefore, the technology often has to have enough proven value to offer, before decisions and investments are made. Especially in large organisations, where investments in the wrong solutions or technologies has serious effects on a large amount of people, there needs to be a form of security in the investments. It can be hard to correctly estimate how the future will look, but many theoretical approaches are available for doing this type of forecasting. In relation to the research in this report, a forecasting theory is needed to verify the basis for IoT in Copenhagen, and the need for IoT platforms. The following chapter will present a review of the most common forecasting theories, and the two most relevant ones will be selected, to be used in the analysis.

4.2.1 Overview of forecasting theories

There are a number of ways to approach forecasting, depending on the information available, and the technology in focus. The resources available also largely determines the type of theory chosen, as a technology forecast performed by a large standardisation organization or a global consultancy firm, will be much more extensive than that of a smaller company, or the one made in this report. But the less extensive forecasts also have importance, as the indications shown in these might prove a need for another and more thorough round of forecasting, thereby paving the way for a substantial amount of insights on the technology (Firat et al, 2008).

The field of technology forecasting is not new. The methods and theories have been developed for over 60 years, and had their origin in the area of military intelligence, where the objective was to gain insights in the capabilities of enemies' technology and military equipment (Cho, 2013). It has since then evolved to focusing more on market competitiveness and can now be separated in two categories; quantitative and qualitative theories.

Quantitative forecasting theories are heavily based on precise numerical measurements, and requires solid historical data for either the exact technology in focus, or if the technology is new, historical data of a similar technology. When this data is not available, qualitative alternatives have to be used. These theories rely on human experience and judgement, and will often include input from experts, and research of the potential users of the technology (Windekilde, 2015). Another way of categorizing forecasting theories is to separate them between the ones that are exploratory and those that are normative. Exploratory forecasting theories are focusing on what might be in the future. The point of departure is therefore what the situation has been up until current times, and how the future could potentially look. In contrast, normative forecasting theories will start by focusing on a set of needed requirements in the future, and work towards the present, to see how these requirements will be met (Cho, 2013). Exploratory theories might be more useful for situations where a technology is assessed on a general level, and can be a bit naïve, whereas normative theories applies well for situations where specific goals needs to be fulfilled (e.g. for an investment), but might be too complex for general use. The optimal solution would therefore be to forecast a technology with a combination of both normative, explorative, quantitative and qualitative theories, but this requires a lot of resources.

In literature related to forecasting, the following theories frequently appear (Cho, 2013)(Firat et al, 2008)(Slocum & Lundberg, 2001):

- **Delphi method**

The Delphi method is widely used, and contains a number of iterations, where experts within the field of study is included in both the assumptions at the basis of the forecast, and the review of the possible future scenarios (Firat et al, 2008). This theoretical approach is useful for forecasting 20-30 years ahead, when historical data is not available (Cho, 2013). The theory includes both normative and explorative elements, but mainly has a qualitative approach.

- **Backcasting**

The elements of backcasting are very similar to those of normative theories in general; future scenarios are established, and possible routes towards these scenarios are then analysed (Cho, 2013).

- **Data mining**

Data mining is commonly numerical, but text mining also exists (Firat et al, 2008). Especially with the developments in cognitive computing and extensive analytical capabilities, data mining is increasingly capable, but relies on the availability of data. The outcome of data mining is a generalization which indicates a future scenario, based on historical trends.

- **Growth curves**

Growth curves are a way of visualizing the life cycle of a technology, and identifying how it will perform in the future, based on the current stage of growth. It is therefore exploratory and can be based on data from similar technology trends (Cho, 2013).

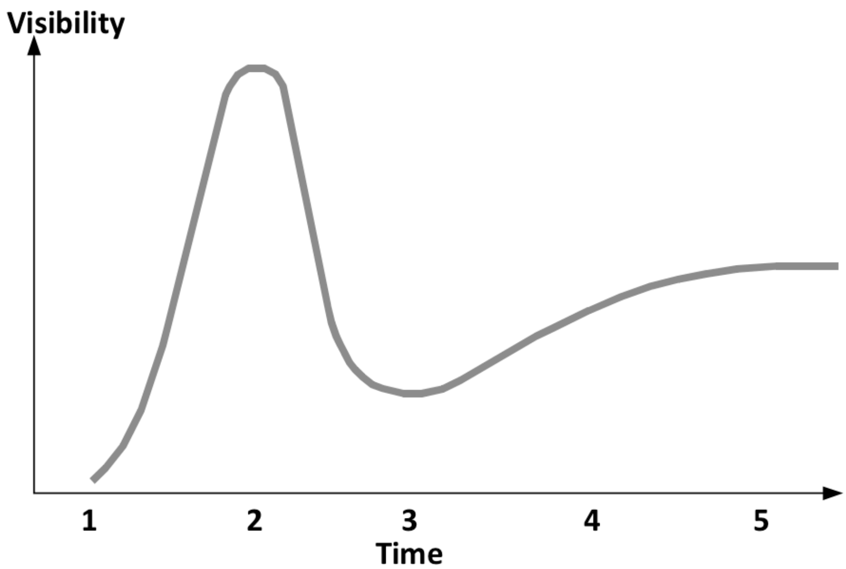
- **Maturity models**

Not typically referred to as a forecasting theory on its own, maturity models expand on the different levels of adoption and where on the forecasting scale a technology, business, market or user group is situated (Windekilde, 2016). It can therefore be considered an extension of the growth curve, or life cycle assessment (Slocum & Lundberg, 2001).

It is clear that some theories are more relevant in relation to this research, both in terms of the resources available, and the purpose of performing the forecast. The theories chosen needs to combine explorative and normative approaches, in order to see how the future potentially looks and how to get there. But they also need to rely on information available through literature research. Based on these criteria, a combination of growth curves and maturity models is chosen. The following segments will describe their contents in more detail, and propose how they can be applied in the analysis.

4.2.2 Growth Curves

The S-shaped curve is a common form of growth theory for forecasting. This is a curve, which originated in relation to biological organisms, and has been found well-fitting for the evolution of technologies as well (Cho, 2013). Another common aspect of growth curves, can be found in the hype cycle, typically used to illustrate the market potentials of new technologies. It deals with the over-estimation of technological capabilities, which is a failure in many forecasts, leading to damaged credibility of the technology (Van Lente et al, 2013)(Windekilde, 2016). This means, that when a technology is at the high point of a hype cycle, investments and development has a higher chance of failing to match expectations, rather than if these efforts are made when hype is at a lower stage. But the hype attracts attention and makes development possible, so it is not all bad. The analytics and consultancy company Gartner publishes an annual hype cycle of the most dominant technologies in the media and on the market. The purpose of this hype cycle is to make it clear that the choice between investment and ignoring a technology should not be based on the hype it receives (Linden & Fenn, 2003). Figure 10 illustrates the hype cycle and its five stages, which will be described in the next section (Linden & Fenn, 2003).



Figur 10 – The hype curve as used by Gartner (Linden & Fenn, 2003)

1. **Technology trigger**

In the beginning, the technology is unsubstantial, and no actual solutions using the technology exist on the market. This moves into the rise of the early products and services, which are often high priced and not adopted by the market yet.

2. **Peak of inflated expectations**

More vendors enter the market, and the usefulness of the technology is tested in larger companies. The experimental phases might lead to some unwanted findings, and these realizations can cause negative media attention, as the value created does not live up to the hyped expectations.

3. **Trough of disillusionment**

As the negative attention increases, the feedback from this is used to improve and mature the technology, and synchronize the expectations for the technology with its actual capabilities.

4. **Slope of enlightenment**

When the capabilities are more in tune with the hype, adoption increases. In this stage, adoption will often be at 5% in the beginning, and reach around 30% when entering the plateau of productivity.

5. **Plateau of productivity**

Reaching the plateau of productivity includes mainstream adoption of the technology. When this happens, the hype will eventually disappear, as the technology and its capabilities are widely recognised.

The speed at which a technology moves along the hype cycle is different, depending on the disruption it causes for current business processed, and the usefulness it provides.

Among the weaknesses of this theory is the simplicity of its design, generalizing the hype trend of all technologies placed on the graph. Not all technologies will go through the mentioned stages and follow the same trend, so the validity of the forecast is not completely optimal (Van Lente et al, 2013). Furthermore, the emergence of new technologies can have a big impact on the hype of others, indicating that there is an amount of uncertainty in expecting technologies to follow the established trend.

In conclusion, the hype cycle is not totally valid and bases a lot of the statements on assumptions. But it is widely used and offers an intuitive visual representation, which is sufficient in relation to forecasting for this report. Especially when used in combination with an overview of the maturity.

4.2.3 Maturity models

Maturity models are normative in the sense that a set of end-goals are listed in the most mature level. It also has more focus on the route towards the end goal, than it has on the end goal itself. It could therefore be argued that it is a form of benchmarking, more than it is a forecasting theory, but in combination with considerations for the potential of the technology, the outcome is a more nuanced insight in the technology and its future potentials.

Maturity models consist of a combination of focus areas and maturity levels in a table form, illustrating the advancement of each focus areas in relation to the maturity levels. An example of a simple maturity model can be seen in table 3 (Windekilde, 2016).

Maturity level	1	2	3	4	5
Focus area 1	X				
Focus area 2			X		
Focus area 3			X		

Table 3 – Example of a simple fixed-level maturity model (Author)

The most common variations of maturity model theories are (Windekilde, 2016):

- **Fixed-level maturity models**

This type of maturity model has a set number of maturity levels, each describing the situation or capabilities relevant for that maturity level (Van Steenbergen et al., 2010). The model has fixed-levels, meaning a focus area cannot be in more than one maturity level. As an example, a focus area for a smart city maturity model could be the city management status. Under this focus area, the maturity levels could range from "isolated in silos" on the lowest level, to "a sustainable and open system of systems" on the highest level (The Scottish Government, 2014). The example in table 3 also represents a fixed-level maturity model. An advantage of the simplicity in this model is that it can be used for benchmarking technologies (Windekilde, 2016).

- **Continuous fixed-level maturity models**

A limitation of the fixed-level maturity model is that focus areas cannot overlap two or more maturity levels. This means, that in the example mentioned above, even though the city management would be in-between two maturity levels, the model would not allow to illustrate this. The continuous fixed-level maturity model on the other hand, allows for this exact capability, creating a more dynamic model. This makes it possible to use the model more as a planning and guidance tool, rather than a benchmarking tool.

- **Focus area maturity models**

In this last maturity model, the maturity levels are not confined to a specific number. The focus areas each have their own definition of lowest, middle and highest amount of maturity reachable, and the outcome is a model with a better understanding of the different capabilities of each focus area (Van Steenbergen et al., 2010). As an example, the maturity of public adaption of a technology might require more time and incremental development than the maturity of the business adaption of the technology. The first focus area could therefore have a wider scale of maturity than the second.

The three maturity model variations each have their strengths and weaknesses. In relation to forecasting IoT platforms in Copenhagen, a nuanced overview like the one achieved in a focus area maturity model might be too extensive. The optimal theoretical model should therefore be either a fixed-level or continuous fixed-level, depending on the requirements of the focus areas. The final choice of maturity model will therefore be made in the analysis, when the focus areas have been determined.

The concluding part of the theoretical framework is the business model. The considerations for which specific business models theory to use in the analysis will be presented in the following section.

4.3 Business models

The IoT technologies, and the technological evolution in general, brings with it a vast amount of possibilities for creating new services, products and solving problems in novel ways. The business models in many sectors, which are not directly related to the technology sector, are seeing a large amount of innovation, and are being disrupted in many ways. Therefore, business models as a tool for analysing new approaches to value creation, are subject to much research, and technology is playing an integral role in many of the theoretical approaches. One way of looking at business models is that they deal with a company’s mission, the structure of the value chain, a process overview and revenues (Bouwman et al, 2008).

A very popular theory for innovative business models, and particularly used in relation to entrepreneurial businesses, is the Business Model Canvas (BMC) by Osterwalder and Pigneur (Osterwalder & Pigneur, 2010). One of the strengths of this theory is the graphical overview it establishes of not only the different elements of the business model, but also the dependencies between them. The BMC consists of nine building blocks, which illustrate the fundamental elements of the business. These are as follows (Osterwalder & Pigneur, 2010):

- **Customer segments**

This includes the target groups and customers, which the business is trying to reach. Furthermore, it can include an overview of the market segmentation, and the circumstances related to the market position the company aspires to take (e.g. a niche market or multi-sided market).

- **Value propositions**

The product or service, which the company offers in order to create value for the customer segment.

- **Channels**

The way of reaching the customer segments, not only with the end product or service, but also with communication.

- **Customer relations**

In contrast to the Channels building block, this building block deals more with the types of relationships the company wants to create with its customers.

- **Revenue streams**

The types of revenue-making a company monetises from through the customer segments. This block also deals with the pricing structures used by the company.

- **Key resources**

The most important elements of the company, in order for it to realize the value proposition. These can both be intellectual, physical, human and financial.

- **Key activities**

Much similar to key resources, but these are the most important processes of the company, such as platform provision for an IoT platform, or production for a hardware provider.

- **Key partnerships**

These are the suppliers and partners, which the company deals with.

- **Cost structure**

The costs involved in the business operations. The cost should be compared to the revenue streams to analyse the profitability of the business.

The simplicity and overview of the BMC are strong advantages over other, more complex theories, but the lack of a specific focus on the technology involved in the business model is a problem. Furthermore, much of the emphasis in the BMC is on the company itself, rather than the ecosystem of actors involved in the value creation. An alternative business model theory, which includes a technology-focus, as well as a more detailed analysis of the stakeholders included in the value creation, is the STOF-model by Bouwman et al. Here, the business model is divided into four domains, each with a rather complex set of subdomains, but all with the purpose of providing value for the customers (Bouwman et al, 2008).

As illustrated in figure 11, the four domains of the STOF model are service, technology, organization and finance.

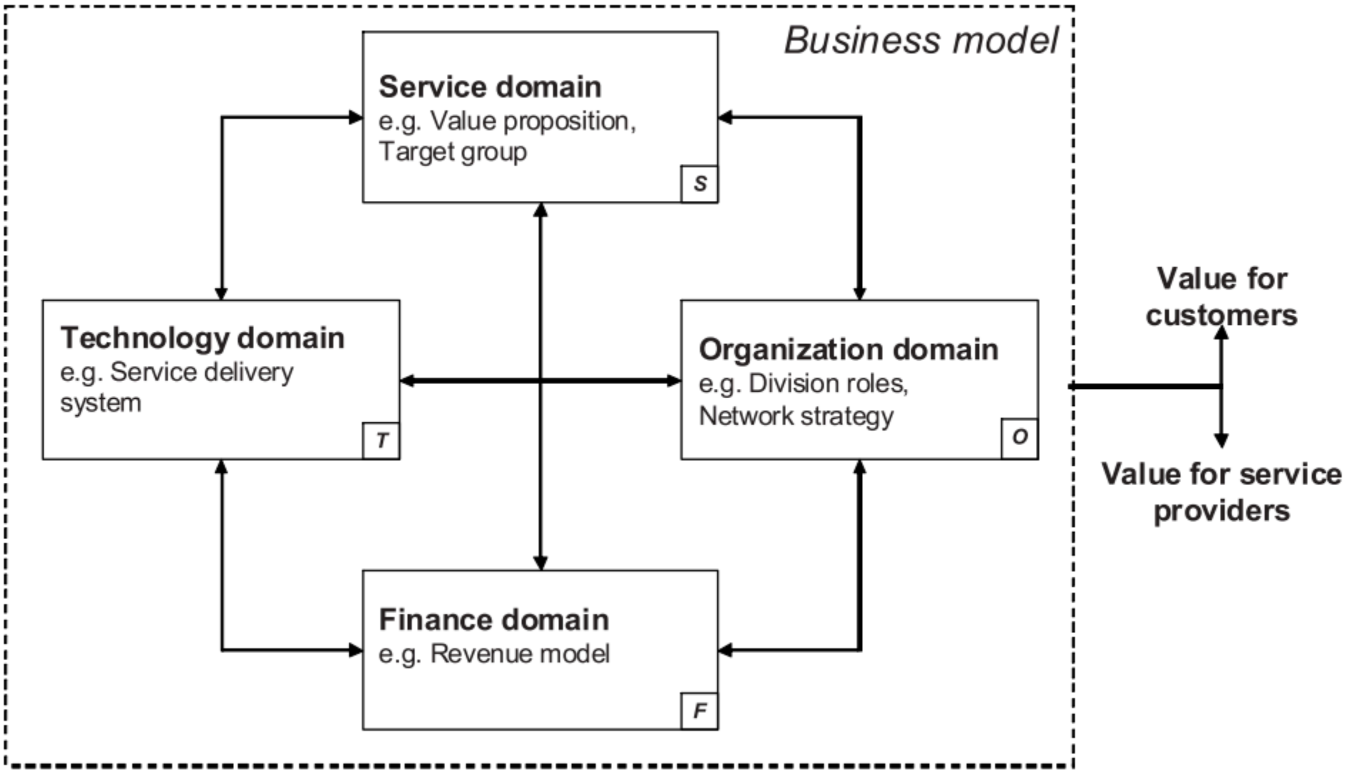


Figure 11 - The four domains of the STOF-model (Bouwman et al., 2008)

The following segments will present each domain according to the theoretical framework by Bouwman et al. A detailed figure for each of the four domains can be found in appendices B1-B4 in the end of the report.

4.3.1 Service domain

In the STOF model, the service domain is mainly focused on the value proposition, but approaches this term with a more detailed view than other business models. It is argued that there often is a difference in the value, which the company intends to deliver, and the value perceived by the customer. The separation in the theory is illustrated in figure 12.

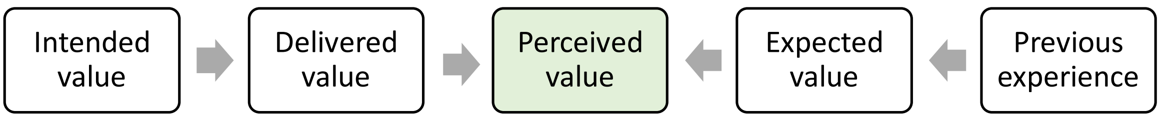


Figure 12 – Value creation in the service domain.
(Author), Adopted from (Bouwman et al., 2008).

The contents of each value element, according to Bouwman et al. is presented in the following section (Bouwman et al., 2008).

- **Intended and delivered value**

The intended value is what is often described as the value proposition, and clarifies what the initial idea behind the service or product consists of. Here, the description might be ambitious to a degree which is hard to achieve in reality. But the intended value is also what creates the basis and requirements for the design of the solution. When these requirements have to be met, the technological functionalities might limit what can be achieved, resulting in a mismatch between the intended and delivered value. Furthermore, the delivered value also consists of more than the solution itself, since activities regarding customer relations also affect the ways in which value is delivered. Lastly, the capabilities of the value network also have something to say in the value delivery.

- **Previous experience and expected value**

The expected value of the solution is affected by aspects such as pricing structure, company image, and the previous experiences, which customers have had with similar solutions or previous versions of the same solution.

- **Perceived value**

The perceived value is described by the method developers to be the difference between the expected value and the delivered value. There is a give and take between the two, meaning a lower expectations combined with higher delivered value, will heighten the perceived value. The characteristics of the market segment, of which the customers or end-users come from, also affects the delivered value. If for example the segment is a market niche, the value expectations and customers might be very different from a mass market segment. Lastly, the context in which the solutions is provided and consumed in, the price and effort invested in the consumption of the service, as well as the possible bundle of services in which the solution is offered, all affects the perceived value.

4.3.2 Technology domain

The technology domain describes the technical functionality provided through the solution architecture. The complexity of this domain is heavily dependent on the size and scope of the company, as well as the reliance on external providers. When dealing with IoT platform providers, who often also provide a number of other IT services, this complexity is rather high, and the technology can be challenging to analyse. This will be further elaborated in the analysis chapter.
The main elements of the technology architecture, are described in the following sections.

- **Applications, devices and data**

As the name implies, these are the applications provided for the customers, and running on the technical architecture. The characteristics of the applications can also be discussed in this relation. Examples of these are security, personalization and the interaction with the applications. Access to the applications will be through a form of device, and this has to be clarified in order to both understand and design the solution. Lastly, the data travelling through the architecture also needs to be determined, in relation to the volume and the pace in which it needs to be transmitted.

- **Service platforms**

In many businesses, some functionality is created through the use of middleware solutions. This can both be related to the internal business operations and some of the functionality of the solution provided to the costumers. The characteristics of the platforms can have a high impact on the rest of the technological architecture, as they have to be compatible and reliable in order to be functional.

- **Access network and backbone infrastructure**

The access network and backbone infrastructure mainly deals with the bandwidth requirements of the technical architecture, as well as the types of connectivity and the state of the connections.

4.3.3 Organisational domain

The organizational domain deals with the capabilities internally in the business, but also the external actors, which collaboration and partnerships are made with, in order to improve the value creation. The authors pf the STOF model uses the “value” web term, as the collaborations can be made between many different actors, and across multiple business domains.

The organization of the value network is divided into three categories depending on the closeness of the collaboration and the effort invested from the partners. The first level is the structural level, where the collaboration is essential for the value creation. Second is the contributing partners, where the effort provided fits with the business purpose, but does not otherwise provide extra value. Lastly is the support category, where the collaboration is useful, but the partner is not essential and can be substituted with ease. Figure 13 illustrates this categorisation.

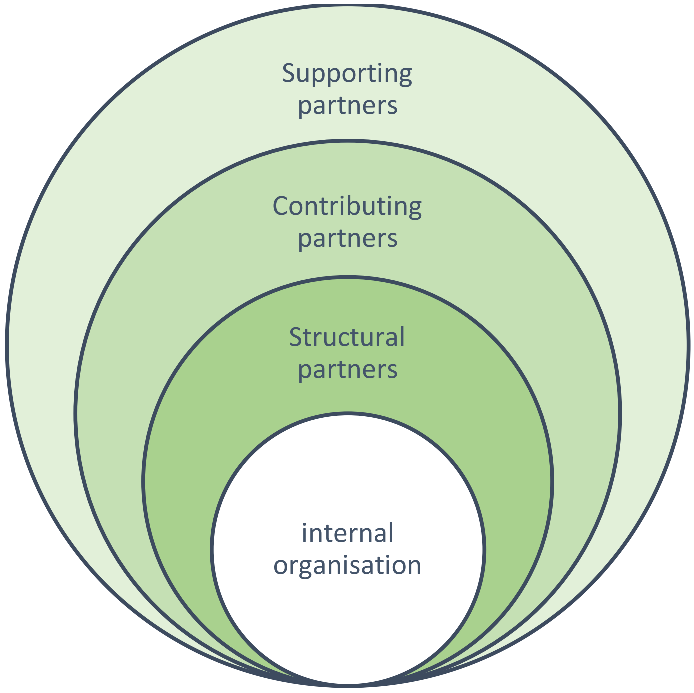


Figure 13 – the three layers of partnerships in the organisational domain.
(Author), Adopted from (Bouwman et al., 2008).

The division of elements in the organisational domain according to the theory is made as follows:

- **Actors and value network**

The actors from the different partnership layers in the abovementioned division, and how they control the value network, affects the organisational structure. This depends on the layer they occupy and the importance of their contribution to the network.

- **Interactions, resources and capabilities**

The amount of interaction between the partners determines the strength of the partnerships. The nature of the resources and capabilities of the partners also needs to be clearly stated, in order to determine their position in the value network.

- **Strategies, Goals and agreements**

Mapping the strategies and goals of the partnerships in the value network is important, but can be hard, as some partners might have hidden agendas. Protection against partners who might not act according to the initial agreements can be done by forming legal documents, which state the rules and limitations for the partnership.

4.3.4 Finance Domain

The financial domain deals with how revenues and costs are created, how they are divided amongst the value network, and ultimately how the pricing structure of the provided solution will be for the customer. There needs to be a sustainable division between costs and revenues, and the actors needs to be rewarded based on the amount of costs they are responsible for, in order for the network to function optimally. The domain can be separated in the following elements:

- **Investment capital and revenue sources**

The activities, and especially the technical architecture, needs capital in order to be realized and create value for the customers. When these investments are placed and the business is active, the payments from customers form revenue sources, but revenue can also be attained through other sources (e.g. subsidies).

- **Costs and Performance indicators**

The performance indicators are useful for overseeing the progression of the business, and to spot areas that are problematic. If costs for example prove too high, and revenue streams are not meeting the wanted levels, return on investment for investors does not succeed. As mentioned in the introduction to the domain, costs highly affect the financial balance of the business model.

- **Risk sources**

There will always be an amount of risk and uncertainty involved in running a business, but the plans and approaches for dealing with these, can determine whether the business survives the risks or not. All elements of the business model might potentially raise a financial risk, which makes the risk assessment an important element to focus on.

- **Pricing**

The pricing strategy can take many forms, especially when dealing with IT services that has varying demands from costumers. Some examples are competitive pricing, value-based pricing and personalized pricing.

4.4 Chapter conclusion

The review of common practices in relation to the three focus areas of the theoretical approach has revealed a set of specific tools, which can be applied in the analysis. This will make it possible to include the needs of the city, with the potentials of the technological solutions, and based on these findings, evaluate the business model of the value network related to the IoT platforms in Copenhagen.

The following chapter will present a market overview, including the empirical data gathered for this report

5. Market overview

The market review is based on research papers in the areas of smart cities and IoT solutions. Many of the providers of services in these areas, are multinational companies, so the review will include a global, national and local city perspective. Two papers related to smart city activates are by ARUP & CEDI (2016) and COWI (2016). ARUP & CEDI looks at the national level, by focusing on four different cities, including Copenhagen, ending with a set of recommendations for Denmark in relation to achieving value from smart city solutions. This research paper was also used in the state of the art chapter related to smart cities earlier in this report. COWI presents an analysis of the infrastructure for smart city solutions in Copenhagen. Here, the focus is on the technological requirements for these solutions, including the use of IoT. IRIS Group (2016) and Ericsson (2015) focus specifically on the use- and adoption of IoT solutions among Danish companies, and Telia & Arthur D. Little (2017) looks at the growth potential of IoT in the Nordic countries. These papers, in combination with global market statistics for smart city, IoT and IoT-platforms from IDC (2017), Gartner (2017), Forrester (2017) and Navigant (2017), are combined with the purpose of identifying the market conditions for IoT platforms in relation to smart city initiatives in Copenhagen.

The chapter will firstly focus on the characteristics of the smart city initiatives in Copenhagen. The main types of market actors and stakeholders will then be presented, followed by market trends on both global-, national-, and city levels. In the end of the market overview, barriers, opportunities and key resources will be reviewed. In the second part of this chapter, Interviews conducted for te research in this report will be presented.

5.1 Market conditions

The city of Copenhagen inhabits around 600.000 people, and in the greater metropolitan areas, around 2 million, making it the largest city in Denmark (COWI, 2016). The city is governed by a public representation (Borgerrepræsentationen), which divides the responsibilities of managing the city between seven committees, each with a mayor as the leader. The seven focus areas of the committees are finance, technology and environment, culture and leisure, children and youth, health and care, social services, and employment and integration (Københavns Kommune, 2016b). The majority of the work towards use of IoT and smart city initiatives fall under the committee for technology and environment, and in 2014 the CPH Solutions Lab, as previously mentioned, was formed with the purpose of testing and developing technological solutions for the city's challenges. The vision of the unit was to create a publicly managed hub, where private partners, academia and the public collaborate on the use of technology in the city. This is relevant, since smart city projects benefit from such "four strand helix" collaboration, where both municipalities, the private sector, academia and civil society join forces, to create value for the entire city (ARUP & CEDI, 2016). The idea for CPH Solutions Lab originated in the "Copenhagen Connecting"-concept, which was a smart city strategy developed by the city of Copenhagen, resulting in Copenhagen winning the World

Smart Cities Award in 2014 (ARUP & CEDI, 2016). The activities of CPH Solution Lab will be elaborated in the interview description in the end of this chapter.

In Copenhagen, becoming a smart city is not a goal, but rather a way of achieving goals related to quality of life and economic growth (COWI, 2016). The climate and environment in particular is a focus area used to improve the city. In this relation, the Climate Vision for 2025 is produced by the city. In this vision, the city is focusing on the development through three overall goals (Københavns Kommune, 2015):

1. **Being a vibrant city**

Work towards this goal is focused on creating good circumstances for everyday life, aiming at becoming the most bike-able city in the World, and by bringing more nature into the city.

2. **Being a city with an edge**

The diversity of both inhabitants, buildings, environmental elements and much more is what creates the culture of the city. The contrasts should therefore be accommodated for and developed, in order to create a more interesting and vibrant city. This can be achieved by focusing on flexibility and creative use of the city, where short-term projects also are welcome, and entrepreneurial spirits are testing new things in the city. Furthermore, the contrasts existing in the city must not divide the society, and all areas should be attractive in their own way.

3. **Being a responsible city**

Becoming CO2-neutral is a goal, which also creates jobs, less noise, cleaner air and healthier citizens. The top priority is therefore to work towards this goal, but responsibility also involves less waste of resources through more re-use and sharing, as well as responsibility in relation to creating a city that can withstand the elements of the climate in the future.

These goals are covering a wide variety of city activities due to their general focus, which also makes it possible for IoT and smart city solutions to be used in many relations. This can both be an advantage, as the potential value creation is large, but it also has some limitations in relation to the difficulty of utilizing solutions on a larger scale, across all the various elements that needs to be improved. The following section will focus on the main types of actors on the market.

5.1.1 Market actors

There are both device developers, service providers, platform operators, software developers, network operators, and service users on the market (Kim et al, 2014). Another way of looking at the market actors is to divide them in enablers, creators and operators (IRIS Group, 2016). Here, the enablers are the infrastructure providers, as well as the many local branches of global IT companies, that are providing IoT services. The creators are the developers and providers of specific IoT products and solutions. The operators are the actors who use the IoT solutions to improve own products or processes.

In an example where Copenhagen uses a waste management system based on IoT sensors in trash cans, the city is the operator of the solution, and the service user. The company providing the IoT solution, includes both device- and software developers, and falls under the creator category. If this solution was to use capabilities of an IoT platform for element such as data analytics or dashboards, the platform provider would be the enabler. But the data also needs to be transmitted over the telecommunication infrastructure, so a telecom such as TDC would also be involved as an enabler (Mikkelsen, 2016).

The large amount of market actor types, combined with the multitude of competitors in both the creator and enabler categories, makes for a fragmented market. However, consolidation and partnerships on the market is increasing, as the IoT platform providers in particular are striving for larger market shares by providing complete suites of IoT components (IRIS Group, 2016). From the city's perspective, the market competition makes it unlikely that the city government can implement, manage and maintain network infrastructure as cheap as the private enablers, making partnerships the most relevant option (COWI, 2016). The city has potential of being a powerful market player due to its size. The public sector is large both on a national level and in relation to municipal governments. In general, the municipalities receive around half of the national public budget, and thereby account for 57% of the GDP (ARUP & CEDI, 2016).

The IoT solution operators are often businesses, or in case of smart city initiatives, the city management. This results in around 70% of the potential for IoT in Denmark to be within the B2B sector (IRIS, 2016).

5.1.2 Market trends

The global marked for both IoT and smart cities is growing. For smart city solutions and services, the global market is estimated to be $40.1 billion in 2017, with an increase to $94.2 billion by 2026 (Navigant, 2017). In Copenhagen, the amount of jobs in smart city companies alone was estimated to be 19.500 people in 2016, indicating a substantial market in Copenhagen as well (ARUP & CEDI, 2016). In relation to suppliers of smart city solutions, Navigant Research rank Cisco and Siemens as global market leaders in 2017, with Microsoft, IBM, Hitachi, Huawei and GE among others, as contenders (Navigant, 2017).

IDC estimates the global market for IoT to be around $800 billion in 2017, and to nearly reach $1.4 trillion in 2021 (IDC, 2017). Furthermore, the Danish GDP has potential to grow with $13.7 billion in 2030, if IoT is used more (IRIS, 2016). Global market leaders of IoT software platforms in Q4 of 2016 was found to be IBM, PTC, GE and Microsoft, followed by Amazon Web Services, Cisco Jasper and

SAP as strong performers (Forrester, 2016). The market position is based on current offerings, strategy and market presence. However, looking exclusively on market shares, Microsoft, Amazon web services, and Cisco Jasper are the most dominant, as found in the state of the art research in this report.

This is combined with an increase in devices connected to the internet, which is expected to reach 20 billion devices by 2020 (Gartner, 2017c). Furthermore, the average number of connected things is three per person in the Nordic region, which is very high on a global scale. Additionally, there is a strong business relationship across the Nordic region, benefitting the individual markets (Arthur D. Little & Telia, 2017).

In relation to cloud services, which much of the functionality in the IoT platforms is based on, the market shares for infrastructure as a service (IaaS), and software as a service (SaaS) accounts for large parts of the cloud market on a global scale (Gartner, 2017d). Where IaaS provides large solutions including servers, storage and networking hardware, the operators providing SaaS operate their own infrastructure and applications, providing the finished software solutions in the cloud (Rouse, 2017). In between these two models is the platform as a service (PaaS), where the infrastructure is provided, along with a number of additional functionalities, as found in the state of the art chapter. PaaS covers a smaller part of the global cloud market, but is increasing, and is expected to reach a market size of $14.8 billion in 2021 (Gartner, 2017d).

The actors on the cloud market, including IoT platform providers, are increasingly offering their services in new subscription categories, to meet the varying demands related to flexibility. An example hereof is the Cisco Kinetic for Cities platform, where the services on the platform are provided in three categories; the base offering includes things as a service (TaaS), the second category is domain as a service (DaaS), and the last is the business as a service (BaaS) (Cisco, 2017a). TaaS covers one type of sensors from one vendor, whereas DaaS allows multiple types of sensors in one domain (e.g. waste management) to be combined and integrated, and BaaS combines sensor data from multiple vendors, in multiple domains (Cisco, 2017a).

5.1.3 Market barriers

There are a number of barriers on the marked for IoT and smart city technologies. The first one deals with the uncertainty in relation to the technologies. Low maturity and standardisation are among the main reasons for this uncertainty in Denmark. However, the security issues surrounding IoT solutions, also play an important role in the uncertainty (IRIS, 2016). In addition to the technological uncertainty, the costs of investment in the solutions creates a financial barrier (Ericsson, 2015). Furthermore, the knowledge gap and lack of competencies related to the use IoT, is prevalent in organizations who could potentially achieve substantial amounts of value through the use of IoT (IRIS, 2016)(Ericsson, 2015).

One of the main barriers for smart city related IoT solutions is the difficulties in advancing from initial testing phase to a full scale implementation. This is especially due to the uncertainty in return of investment on immature technology solutions, as mentioned above (ARUP & CEDI, 2016).

5.1.4 Market opportunities

In Denmark, IoT is often used in industries with a high degree of digitalization, traditions of working with technological solutions, and practical experience with data sharing, both internally and with customers or partners (IRIS Group, 2016). These elements are therefore relevant to improve upon in order to create more opportunities with IoT.

The common trend in the market is that an ecosystem around the IoT solutions is needed, in order to create value with IoT, especially with the uncertainty and immature technologies. The digital ecosystems, where actors collaborate across horizontals, are the keys to ensuring future competitiveness (Arthur D. Little & Telia, 2017). In relation to the IoT platforms, two main types of collaborations or ecosystems are suggested for improved market competitiveness. Firstly, the platforms can either focus on an aggregator ecosystem, where the platform provider includes IoT solutions built by external developers using the platform. In a hypothetical example, Cisco could provide a number of smart city or IoT solutions under the Cisco brand name, even though a separate developer had made the solution, based on functionality of the Cisco platform. Here, the advantage is to create more brand value and security in seemingly using one provider, but potentials for lock-in can be problematic, and the ecosystem can be limited to solution developers who will allow their service to be provided under another brand name. An alternative solution is the second ecosystem approach; the marketplace ecosystem. Here, the platform is used to gather solutions, but the platform customers interact with the separate solution providers, not the platform itself (Arthur D. Little & Telia, 2017). This type of ecosystem is more open, and provides more agility for the customers to select and opt out of individual solutions, without having to find a new platform provider as well.

The second part of this chapter will present the three interviews, including an overview of the companies, the background of the interviewee's, the purpose of the interviews and the main findings.

5.2 Interviewed companies

As mentioned in the methodology chapter, the interviews should cover both the city's perspective, the platform provider's perspective, and a neutral third party, with experience in technological projects combining the two perspectives. The interviews will be presented in chronological order, as they were conducted. When referring to the interviews, the specific appendix in which the interview is located, and the time stamp of the quote, will be stated.

5.2.1 Interview with Sune Fredskild from CPH Solutions Lab

As previously mentioned, CPH solutions Lab is a unit under the municipality of Copenhagen, dealing with development of technological solutions for the city's operations. CPH Solutions Lab is positioned as a division of the technical and environmental committee, and has five key areas of focus. These are as follows (Appendix A1 – 21:30):

- Environment and climate
- Lighting and city life
- Humans and flows
- Data driven operations (big data and sensor use)
- Digital services (e.g. communication with citizens on bus stop monitors)

Their activities in these five areas are separated into two domains; one being so-called living labs, which are test areas in the city, and another being data platforms. In the living lab department, they have the Street Lab, which is an area in the centre of Copenhagen, the EnergyBlock, which deals with decentralized energy and block chain solutions, and a workshop for urban production called Underbroen. In the data platform department, they have the Copenhagen Open Data platform, which is a data portal, a data marketplace developed in collaboration with Hitachi called City Data Exchange, and lastly, they are a part of an international innovation challenge for developing an IoT platform for multiple Cities (CPH Solutions Lab, 2017). The IoT platform for cities seems like an ideal focus are for the research in this report, but the development is at a very early stage, so very limited information is valuable.

Sune Fredskild is a development consultant who has a background in city planning, and has been with CPH Solutions Lab for two years.

purpose of interview

The main purpose of conducting the interview was to understand the needs of the city and how they work with technological solutions in relation to smart city and IoT initiatives. The interview was semi-structured, where a list of questions was used to guide the conversation. These questions firstly concerned the problems that CPH Solutions Lab work with currently, and the experiences gained from working with them, with a focus on the technological aspects. Secondly, questions were asked regarding the partnerships and relations between Copenhagen Solutions Lab and the private market, and lastly, questions about the requirements for value creation in Copenhagen.

Interview resume

Copenhagen does not have a smart city vision. They focus on a number of challenges within the city management, and see how technology can be used to improve these situations. Furthermore, they test and innovate with the technologies to identify their potential, and to become a leader in the field of technology usage. In these tests, collaborations are made between the private market and the city government, where dialogues and developments are in focus. There are a lot of complications in relation to finding technologies that can be applied to heterogeneous problems, and the idea of going all-in on one technical standard such as Wi-Fi is not realistic at all. Furthermore, the city is moving more towards service-based deals, rather than investing in technical hardware themselves.

Internally in the city management, systems are in silos, and there does not seem to be a need for joining data from completely different departments, such as elder care and traffic lights. But CPH Solutions Lab recognises that some cities are testing these platforms, and they seem promising in some regards. Having a platform to control the city will require the city to change a lot of their processes, and this creates a barrier for adopting such a platform. However, the Copenhagen Open Data-platform is sometimes used by the city government to find data sets, which would otherwise be hard to locate and retrieve from one of the many departments, indicating a potential value presented by platform solutions.

A recording of the interview is available in appendix A1.

5.2.2 Interview with Morten Kjeldgaard from Netplan

Netplan is a consultancy firm with focus on technical solutions. The company was established in 1994 and works with project management, procurement, security and technical reviews, in relation to five focus areas listed below. They charge kr. 1.500 per hour of consultation, which means their common clients are rather large.

1. **Telecommunication**

Procurement of subscription plans for large organisations and helping companies navigate in the Telecom market.

2. **Tele services**

Call centre functionality in various scales.

3. **IT infrastructure**

Network solutions for large organizations. E.g. if a company needs to link two physical departments separated over long distances.

4. **Telehealth**

Telemedicine solutions and solution innovation. Examples of focus areas are lung capacity testing equipment for home usage, and a national wound journal, which makes it possible for healthcare workers to upload photos of wounds to a platform where wound experts evaluate the necessary treatment in an efficient way.

5. **Smart society/IoT**

Standardisation efforts and universal access and service. Recent projects also deal with mapping network coverage in various geographical locations and an IoT network for utilities in the municipality of Frederiksberg.

Morten Kjeldgaard is a partner in Netplan and works as a consultant with main focus on IT infrastructure currently, but is also a part of projects related to telehealth and smart society. He has a background in economy and public sciences, and has been a part of Netplan for 21 years.

Purpose of interview and main questions

The purpose of interviewing a consultancy firm was to reach a person who had experience with not only the technical development in relation to IoT, but also the business aspects and practical issues regarding investment in new technologies. The interview had the approach of understanding Netplan and their focus areas, and along this focus, understand how IoT platforms meet obstacles and opportunities. Like the interview with CPH Solutions Lab, it had a semi-structured form, with questions guiding the conversation. In general, there were four topic areas for the questions: IoT, Smart cities, IoT platforms and more specific questions regarding the procurement and market analytical elements of the deals being made.

Main findings

It was found that a lot of IoT projects are a part of the consultancy work Netplan is involved in, and that there are obvious benefits in some of the cases. But there is also a lot of hesitation in relation to both security and the maturity of the technology, making it hard to produce business cases that are in favour of the IoT solutions in order to get funding. But the public sector is a very relevant area to both test and implement these types of solutions, due to the size it has in Denmark and due to the political efforts that can be made to focus the value creation on more than solely financial benefits. The public sector, however, does not have technological development as a key competence, making it ideal to collaborate with IT companies, in order to solve the problems of the cities. These collaborations can be made in many ways, and there is no single answer to the most optimal solution, so it requires substantial needs and motivation from both sides to utilize the technologies to the fullest. The same goes for implementing an IoT platform for city management. In such a case, there will both be negative and positive elements, but a lot of value can be created, if the platform supports the needs of the city, and the city is open to disrupt and reorganize the current way of management.

A recording of the interview is available in appendix A2.

5.2.3 Interview with Bo Finnemann from Cisco Systems

Cisco is among the largest IT providers in the world, with more than 380 offices and 71.000 employees positioned in 169 countries. They had a total revenue of over $49 billion in 2015, and an annual growth of 4%. In Denmark, their office employs 125 people, and the revenue is $300 million. (Høeg, 2017)

Cisco provides an IoT platform, which has been described in the state of the art chapter of this report. This platform is specifically focused on smart city solutions and city management operations, which makes it additionally interesting to get their input in relation to IoT platforms in Copenhagen. They are also in a partnership with the city of Copenhagen and TDC, in regards to development of IoT solutions. A proof-of-concept of their platform, previously known as the Connected Digital Platform, which can be seen in figure 14, has been implemented in the Danish Outdoor Lighting Lab (DOLL) in the municipality of Albertslund.

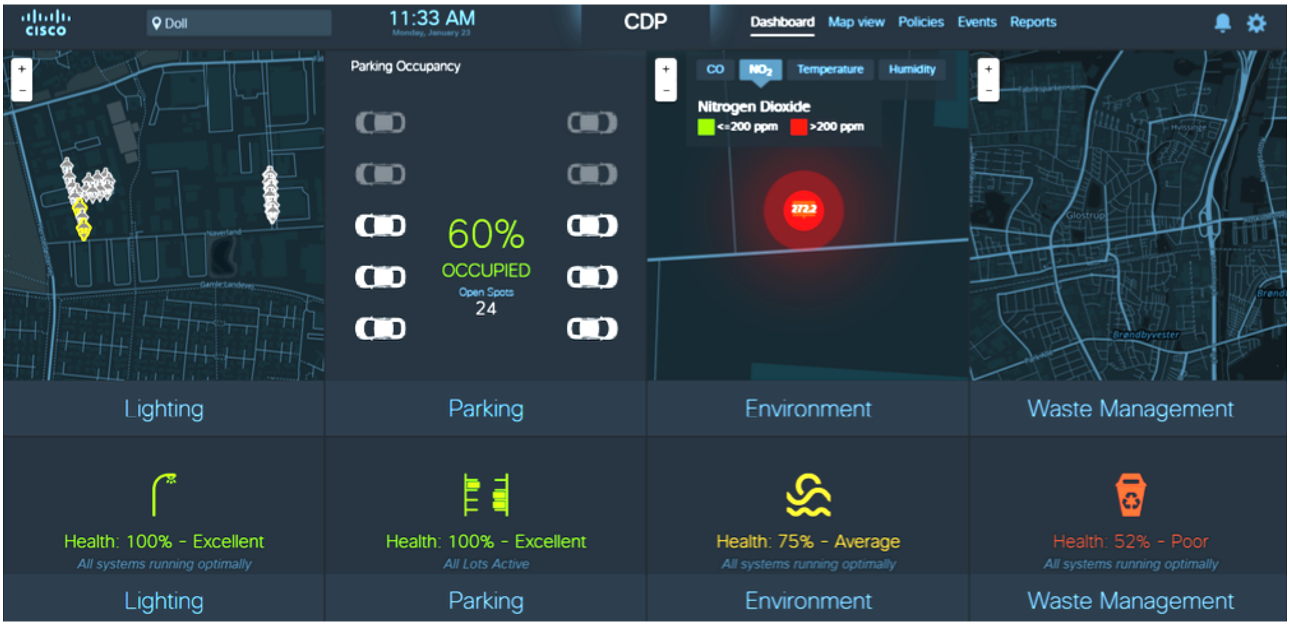


Figure 14 – Interface of the Connected Digital Platform in DOLL (Høeg, 2017)

Bo Finnemann is a customer solution architect at Cisco Systems in Copenhagen. He has more than 17 years of experience in various roles at Cisco, and has worked with technological development at Ericsson prior to his time in Cisco.

Purpose of the interview

The interview was aimed at attaining the platform provider's perspective on the development of IoT platforms in Copenhagen. The experiences from implementing the Connected Digital Platform in Doll, including challenges and potentials, were in focus, in order to see correlations with the proof of concept and the situation in Copenhagen. Furthermore, the IoT platform market was discussed, in order to understand how the business models can be developed, and which areas Cisco see as optimal for the future of their IoT platform. The interview was semi-structured in form, as the other interviews.

Interview resume

Cisco finds the development of IoT in scales of cities, has reached a situation of deadlock, in the sense that network infrastructure investments are needed to develop solutions that provide sufficient value, but at the same time, the solutions are needed to justify the investment in network infrastructure. They see the solution to this, as a research effort in the proper solutions and their use cases. This research needs to be done in multiple domains and integrate value horizontally across verticals of the city. Cisco believes a lot of value in such integrations can be found by focusing on the citizens' needs. They think that this process will take a couple of years, and have a strategy of staying competitive amongst other IoT platforms, by focus on maintaining an open platform through APIs, and not become locked-in to specific suppliers of either sensor solutions or applications.

A recording of the interview is available in appendix A3.

5.3 Chapter conclusion

The market overview indicated that the potential market sizes for both IoT, smart cities and IoT platforms is increasing globally. The markets are characterized by a high number of suppliers, and is affected by the uncertainties present in relation to technological capabilities, as well as the return of investments. The adoption of IoT in Copenhagen and Denmark is increasing, but the barriers in relation to comprehending the value potentials of the technologies, as well as the uncertainty of the immature technology is also present here. Forming ecosystems around the IoT and smart city solutions, allowing for agility in the services, and focusing on additional goals besides financial gains in the investments was identified as key elements for a successful evolution of the technology in the market. The interviews helped create a more nuanced view of the market actors and their problems. The goals of Copenhagen, the problems involved with public investments in technology, and the adoption of IoT platforms, was among the main findings of the interviews. Generally, there is consensus in the opinion that IoT platforms and their related solutions can create a lot of value in Copenhagen, but there are also a lot of barriers to overcome before the value creation becomes a reality.

6. Analysis

The following chapter contains the final analysis, and will apply the theoretical framework to the empirical data and the researched information, with the purpose of answering the research question. The analysis will begin with a focus on the needs of the city of Copenhagen in relation to IoT platforms, through a requirement specification. The maturity of the IoT platforms will then be analysed, using the hype curve and a developed maturity model, with the purpose of determining the need and future position of IoT platforms in Copenhagen. Finally, the STOF business model theory will be used to analyse the value network surrounding the IoT platforms, and conclude a set of guidelines that platform providers should follow, in order to create value in Copenhagen.

6.1 Requirement specification

Given the scope of focus in this report, the requirements are not analysed on a detailed level, but on a level which provides an overview of the needs. The requirements are established based on input from the interviewees, research of strategies in the municipality of Copenhagen, existing market research papers produced by consultancy firms, and the state of the art chapter in this report. The theoretical approach will be as described in the theory chapter; going through the stages of requirement discovery, classification and organization, and specification.

6.1.1 Requirement discovery

In Copenhagen, a number of individual IoT solutions are being tested by CPH Solutions Lab, in collaboration with solution providers. Some of these solutions are as follows:

- A waste management system, which uses infrared sensors in trash cans, with SIM cards sending sensor data to a back-end system provided by the solution developer Nordsense.
- Air quality sensors being installed in light posts to identify the level of pollution on specific streets, with the purpose of guiding traffic towards less polluted routes, rather than exclusively planning routes based on time usage. This solution is implemented by Citelum, who is a partner in the Street Lab.
- A smart parking solution, using a camera installed above a parking space, situated behind the city hall. The camera compares the number of vehicles to a reference image, to determine the availability on the parking lot, and notifies the system when spots are free.

These are three examples of IoT solutions, which the city can use to become more efficient through technology. But the solutions vary a lot, both in relation to the users and the purpose, which also results in various requirements for a common platform. However, there can be an advantage in streamlining the implementation processes, as well as value created by combining the data, which is an incentive for using a common platform. CPH Solutions Lab also describe this division in the solutions: "*We have vertical IT-systems, where one is looking at waste management, one is looking at traffic light, and in a completely different department we have the elderly care systems*" (Appendix A1, 8:00). Having this division can limit the value attained from IoT solutions. According to the review by ARUP and Cedi of smart city activities in Copenhagen, the departments in municipal governments needs to be able to cooperate and "*provide a single point of entry to the municipality for solution providers*" (ARUP & CEDI, p. 12, 2016). This is the role CPH Solutions Lab is taking, and involving an IoT platform might improve the conditions for the solution providers.

A trend in the solutions at CPH Solutions Lab is that they are on an experimental stage. This is where the potential of the technologies is being tested, and business cases are being developed, to justify investments. IoT platforms can cater for these conditions by allowing a lot of flexibility in the use of the platform. This flexibility can be in various forms, including possibilities of scaling up solutions, adding and removing extra functionality in modules, and only paying for the usage, rather than purchasing the complete solutions. Furthermore, the latest technological trends need to be supported, including popular constrained communication protocols.

Having one platform, would mean both city planners, solution developers, operational personnel and perhaps even citizens should be able to access the information on the same platform. It is therefore necessary to clearly distinguish the level of access each user type has, and perhaps even provide some of the IoT data on the Open Data platform. There is a lot of smart city value in providing open data (ARUP & Cedi, 2016), as well as value for the citizens in getting digital solutions that they can access through mobile devices or PCs (COWI, 2016). CPH Solutions Lab also notes that having an open data platform has been an advantage: "*the platform is used by the municipality itself, as it is easier to go to the open data platform, than it is to use our own internal systems. This creates value to a large organization, instead of having it in various hidden corners*" (Appendix A1, 23:30). Of course, the data storage should be supported in a way that has regulatory compliance, and does not move the data out of the region (Arthur D. Little & Telia, 2017)(COWI, 2016).

The use case diagram in figure 15 illustrates how the four mentioned users could be connected to the IoT platform.

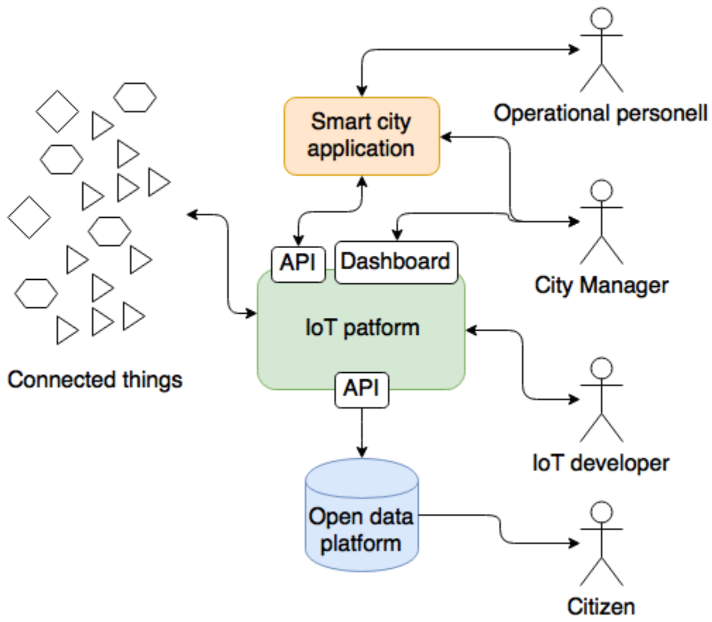


Figure 15 – Use case diagram

Potential activities of the different users are:

- Operational personnel should be able to access data while being out in the city, see trends and update the data based on the insights they gather from their work in the city.
- The city planners would have to be able to log in, search through historic data, use data analytics and combine different data sets. The outcome of the analysis should be made publicly available for citizens to see.
- The developers of the IoT solutions needs to have access to the setup of the services involved in the functionality of the platform.
- The citizens should have access to datasets in order to attain insights about the city, and perhaps even propose possible solutions to problems they see, based on the data.

These four types of interactions with the platform could be made on various devices, ranging from mobile phones, tablets and PCs. A requirement for all users should be that the insights gained from the IoT solutions should be attained in a comprehensible way, and that the specific users should only have access to the data and functionality fitting their user type.

The multitude of users, each with different needs from the platform, indicates that many processes is happening simultaneously, and creates requirements for the availability of the platform. This also makes the rules of the platform highly relevant, as these define what and when functions should happen.

Based on these considerations, the requirements will now be classified.

6.1.2 Classification and organization

Functional requirements on a general level, which the IoT platforms needs to be able to do, are listed below:

1. Provide interfaces for multiple user types
2. Provide APIs for smart city applications
3. Make relevant data available to the open data platform
4. Provide the solutions as a service with flexible pricing
5. Provide functionality in modules that easily can be added or removed from solutions
6. Support constrained alternatives to common protocols
7. Support regional data storage and regulatory compliance
8. Address public concerns in the solutions

Non-functional requirements, or quality requirements, which the IoT platforms needs to be able to do, are:

- **Scalability**

The city needs to learn how solutions work gradually, and copy-paste the successful experiments to other use cases (IRIS Group, 2016). They need this to attain competencies internally on all levels of the organization, and the platform needs to support this gradual development with scalable solutions, in relation to e.g. pay-per-use pricings.

- **Security**

During the interviews with CPH Solutions Lab and Netplan, the lack of security standards appears as a large barrier for the diffusion and maturity of IoT in general. The platforms therefore need to include security aspects in all their service, and indicate these aspects clearly.

- **Usability**

Many companies lack skills in attaining large value from IoT solutions, and CPH Solutions Lab indicated that the municipality is no exception. The platform should acknowledge this gap in skills, and develop interfaces and tools that are easy for the users to work with, in order to lower the effort needed to attain value through the platform.

- **Environmental**

As mentioned in the market overview, the city of Copenhagen has a climate plan for 2025, which indicates the need for becoming carbon neutral and being responsible as a city (Københavns Kommune, 2015). This plan is one of the main driving forces for smart city initiatives, and also the utilization of IoT. IoT platforms will therefore have an advantage, if the positive environmental impact of the solutions is marketed with the platform. Furthermore, the operation of the platform needs to be done in a way that Copenhagen can justify, in relation to a partnership.

- **Openness**

Both Cisco and Netplan describes the modularity in design as an advantage for creating the foundation for collaborations, and attaining an ecosystem around the IoT solutions. They both refer to the complications that lock-in can create, if partnerships are formed based on immature technologies, and highly recommend taking an open approach to the IoT platforms, though APIs and partnerships.

The established requirements will be used in the analysis of the business model. But before going to the STOF business model analysis, a forecast need to be conducted.

6.2 Forecasting IoT platforms

As mentioned in the theory chapter, a combination of the hype curve and a maturity model will be used, with the purpose of analysing the future potentials and capabilities of IoT platforms. The outcome of this forecast will be used in combination with an analysis of the requirements and the business model, to indicate how IoT platforms can contribute to the value creation in Copenhagen.

6.2.1 Hype curve analysis

The hype cycle analysis will be based on the model developed by Gartner Research, as it is widely used and includes a focus on IoT platforms. An important detail of Gartner's hype cycle for emerging technologies is that it looks at technologies on a global scale. The hype level of IoT platforms might be different in Copenhagen, but as was found in the market review, the Danish IoT market is following many of the same trends as the global market.

Gartner Research is among the world leaders in technical research and advisory services, and has a general focus on the technological sector. The hype cycle is published annually, and is part of the Gartner Trend Insight Report, which analyses enterprise- and ecosystem digital disruption (Gartner, 2017a). Figure 16 illustrates Gartner's hype cycle, with the evolution of IoT platforms over the last three years added. These are marked with red arrows.

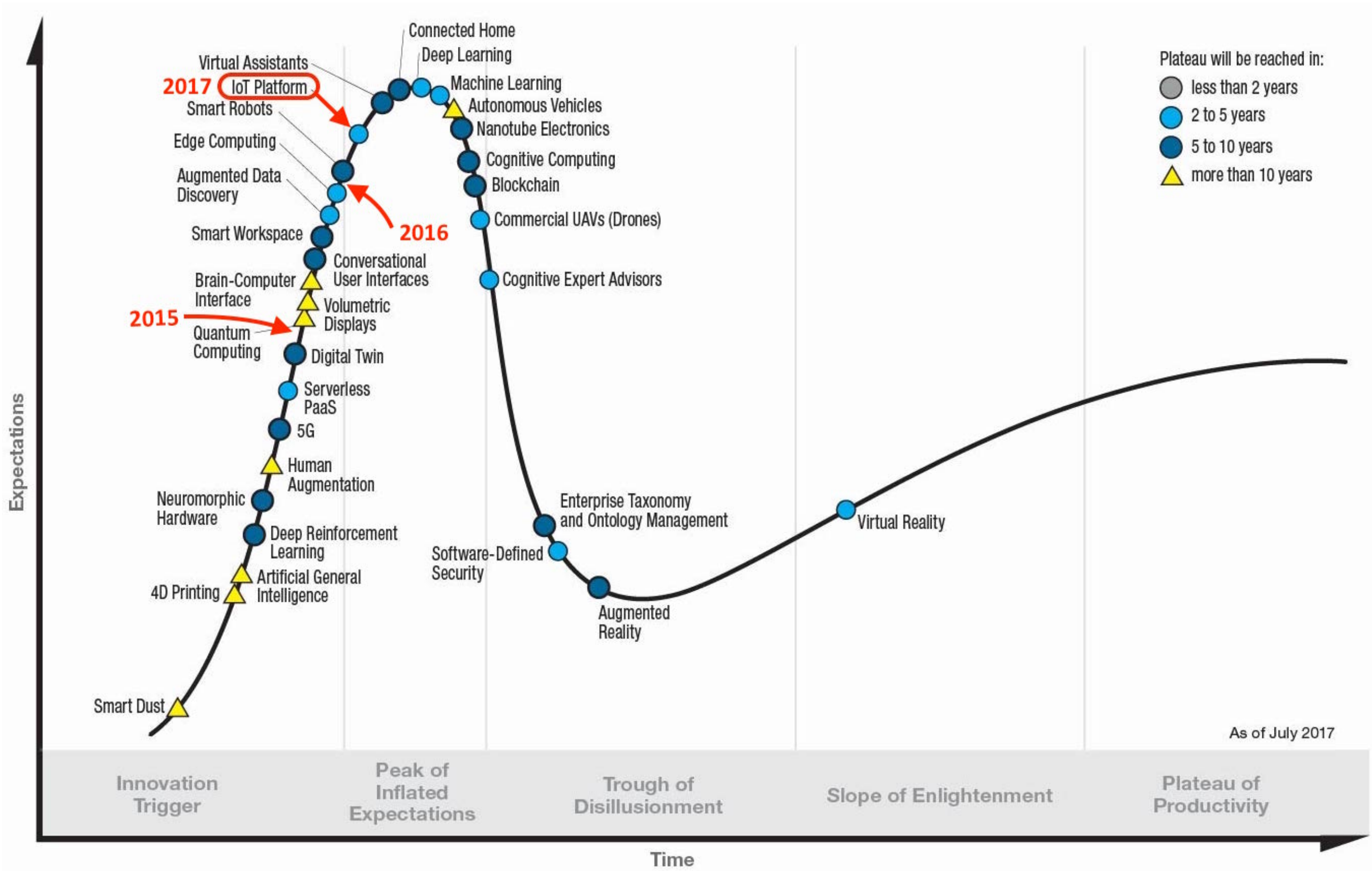


Figure 16 – Gartner Hype Cycle for Emerging Technologies (Gartner, 2017b)

As the figure illustrates, IoT platforms has entered the peak of inflated expectations, and the hype continues to rise. This is also visible with the increasing amount of platform providers, as many cloud- and data analytics based companies bundle their services and offers them on platforms. Companies are experimenting with the platforms, and the findings from these experiments, such as the lack of common standards, and the security and privacy risks, are being covered by the media. Especially the area of security and privacy is causing some negative connotations with IoT, indicating a possible turn in the hype of the platforms, if this area is not handled well. Hacking IoT devices, and forming so-called "bot nets", used to overflow webservers with traffic, has been covered widely in the media. An example hereof is the Miari Botnet, which affected popular sites such as Netflix, Twitter, Reddit, Airbnb and the New York Times, by attacking a DNS server in October of 2016 (New York Times, 2016). However, the hype has continued to rise since this hacking attack, indicating that threats related to privacy and security does not affect the hype extensively.

Between 2015 and 2016, the hype increased quite a bit, almost entering the peak of inflated expectations. But between 2016 and 2017, the increase has been smaller. This happens even though the dot on the curve changed from dark to light blue, indicating that instead of a period of 5-10 years before reaching the plateau, it is now forecasted to happen in 2-5 years. The smaller increase in hype might indicate that the peak is almost reached. If this is the case, effort should be focused at avoiding plummeting into the trough of disillusionment, where the capabilities of IoT platforms is doubted.

When looking at the hype cycle, it is important to note that this hype occurs very early in the life of the technologies. Linden & Finn (2003) illustrates this nicely by combining Gartner's hype cycle with the S-curve and a common adoption curve, as seen in figure 17. Based on this assumption, the adoption and performance of the IoT platforms are in the very beginning phases, and the potential for the technology is therefore looking very good.

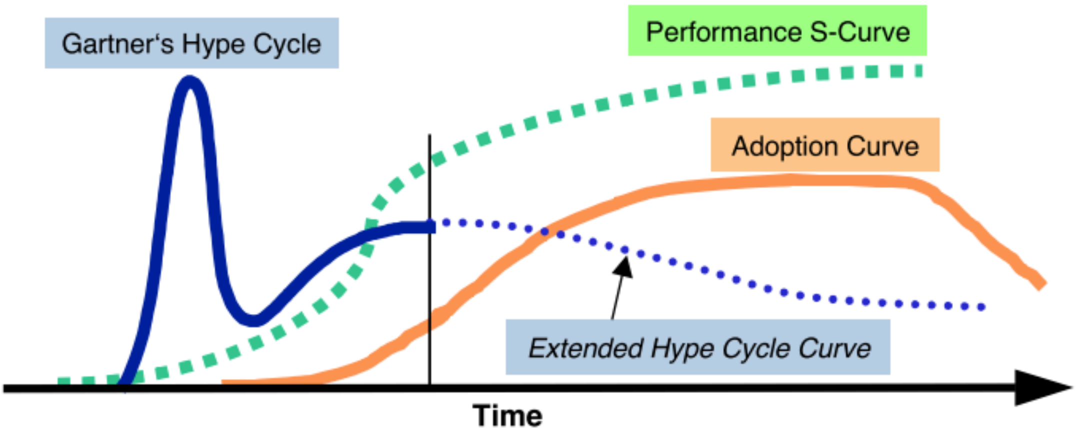


Figure 17 – Gartner's hype cycle compared to the S-curve and adoption curve (Linden & Finn, 2003).

The second part of this forecast will focus on the maturity of IoT platforms, to attain a comprehensive view on the development of the IoT platforms in relation to smart cities.

6.2.2 Maturity model analysis

Maturity in relation to IoT platforms can consist of many elements, as the capabilities and services of the platforms are wide ranging. As found in the research on both IoT in general and IoT platforms, the areas consist of many technological elements. In relation to smart cities, the research also indicated the multi-facetted nature of the area. It can therefore be hard to summarize the most essential elements, and arrange them on a scale in accordance to their maturity, but the following segments will strive to do just that. The analysis is based on a review of relevant existing maturity models, combined with the findings in the state of the art chapter, the market review and the interviews. Based on these elements, the key focus areas of maturity in relation to IoT platforms for smart cities have been selected. The focus areas are as follows:

- Resources and capabilities
- Technologies provided on the IoT platforms
- Technologies allowing use of IoT platforms
- Smart city engagement of the IoT platforms
- Market readiness for IoT platforms

Resources and capabilities, and services provided on IoT platforms

In relation to the resources available in the companies providing IoT platforms, the maturity is very high, as the main competitors are market leading, global technology providers like Microsoft, Cisco, Amazon, and IBM. The capabilities are not locked in verticals, which could be the case with e.g. providing data analytics separately from an IoT hub or cloud storage services. Many of the IoT platforms are based on the dynamic interconnection of the company's other services, and provide these services either by them self or bundled on the platform. The maturity in relation to this is therefore quite high.

The services of IoT platforms listed in the state of the art chapter, can be used as a reference to what a mature platform should contain. Some providers might only have one or a few of these service capabilities, and rely on the users to develop the remaining elements themselves, or find them at other providers. In this case, a platform would not be particularly mature, as the scope of services is low. The market review focused on IoT in the Nordic countries by Arthur D. Little and Telia (2017) look at this in relation to IoT business model maturity, and list the following stages from least mature, to fully matured business models: visioning, innovation, commercialization and ecosystem. In relation to the business model maturity of the IoT platforms in Copenhagen, the collaboration between Cisco, TDC and Copenhagen Solutions Lab can be seen as an ecosystem, where competencies are merged to attain a larger value. However, this is seen as a highly mature example, and is not completely reflecting the major IoT platform provider's business models, as many of these seemingly strive to provide the entire IoT suite of services themselves.

Technologies allowing use of IoT platforms

One of the fundamental challenges of maturing IoT platforms is the technologies on which IoT services are based. In the state of the art chapter, the communication protocols were found to be diverse and in lack of industry standards for development to lean on. CPH Solutions Lab also identify this as a barrier: "*Today, you can't even go to the market with five different smart city problems, and find five sensors that works on the same standard. Some use Wi-Fi, others use LoRa and so on*" (Appendix A1, 36:00). This creates barriers for the adoption of IoT services and solutions, as many of the implementations are experimental, and focus on monitoring or optimizing current solution techniques. Ericsson (2015) proposes a maturity model focused on the enablement of IoT, which contains the following five levels: monitoring, control, optimization, automation, and system autonomy. In the report, the majority of Danish companies are on the monitoring level, and a few are on control and optimization. In a maturity model developed by Gartner (2016), the levels are categorised as: initiating, exploratory, defining, integrated and optimizing. Here, the levels deal more with the specific IoT solutions, whereas the maturity model by Ericsson deals with the purpose of the solution. However, the same barriers apply, and the uncertainty in relation to the technologies is no exception. The maturity of the technologies relies on standardisation efforts as well as diffusion in the market, and at the current stage, the maturity must be concluded as low.

Smart city engagement

Many of the IoT solutions, which the IoT platforms either illustrate as examples of what they can achieve, or already have had success with, are smart city related. But only a few of the researched platforms are, or have parts that are, specifically dedicated to smart city purposes. To analyse the level of maturity in relation to smart city capabilities or engagement, the aspects of smart city evolution researched in the state of the art chapter are used. These are: vision and communication, technology requirements, development of initiatives, and collaboration. A maturity model framework by the European Parliament (2014), used to rank the smart city maturity level of a number of European cities, includes four levels, which can supplement the ones from the state of the art chapter. These are: smart city strategy or policy, project plan or vision, pilot testing smart city initiatives, and at least one fully launched smart city initiative. The maturity levels in this model are focused on the city itself, but can be used to illustrate how well an IoT platform fits with the maturity of a smart city, and thereby improve a form of symmetry between the two. According to the development of smart city initiatives in Copenhagen, and the testing done in Copenhagen Solutions Lab, the maturity is at a rather high level. What is lacking is a partnership-approach from the platform providers side (in exception from Cisco). This collaboration might lead to an ecosystem on the market, where joined forces creates unique possibilities for improving the cities. This would be the highest form of maturity and smart city engagement from the IoT platform providers side, but in reality, they are only in the early levels of engaging in smart city activities.

Market readiness for IoT platforms

The IoT platforms are of course also highly dependent on the market's capabilities of adopting their services. In this context, the findings form the market overview and the hype curve analysis can be used to determine the scale of maturity for this focus area. In the beginning, the market has no knowledge of the IoT platforms, and the maturity is at the very lowest level. As knowledge starts to spread, so does both maturity and hype. Implementations with IoT platforms can then begin on an experimental level, and the hype might get exaggerated due to the imagined potentials of the platforms. When the platforms become used more, the hype will deflate as the realization of not living up to the exaggerated expectations happens. The IoT platforms are currently at a maturity level in between these two stages. The maturity rises with the market adoption, and is at a maximum when the IoT platforms are an integral part of the market.

Figure 18 illustrates a maturity model, which has been produced based on the analysis of the focus areas. It is a continuous fixed-level model, where the orange fields indicate the level of maturity in each focus area. By finding the average maturity of all focus areas, a general maturity is found to be around 2,8, meaning the maturity level is slightly above the middle. This quantification gives a very generalized conclusion of the maturity level, as there is a high variance between the focus areas, but can be used to illustrate that there still is quite a lot of development to do for the IoT platforms to reach a higher potential and value creation.

The maturity model, in combination with the growth curve, shows the very early stage of development, which IoT platforms are in. Forecasting IoT platforms therefore illustrates that there are a lot of uncertainties in their capabilities and that a lot of hype is present at the same time. This seems like an unstable combination, and might affect the hype around the IoT platforms, if efforts for increased maturity is not in focus. However, the value potential by the use of IoT in general, and the platforms as a tool towards achieving this value, would be very good for both the market and Copenhagen. The following part of this chapter will focus on the business model behind the IoT platforms, with the purpose of analysing what it consists of, and to locate areas of improvement.

	Level 1	Level 2	Level 3	Level 4	Level 5
Resoruces and capabilities	Small organization with limited resources and capabilities	Key capabilities available but siloed	Many resources and capabilities, but still siloed	Many resources and capabilities with high ability to integrate them.	Market leading capabilities and resources, in a dynamic and adaptive organisation.
Services supported on the platform	One element of platform capabilities available	Few elements avaialble	Many elements as individual services	Full IoT platform available	Full IoT-platform with analytics and other services supported. Incorporation of substituting and complimentary services possible.
Technologies allowing the use of platforms	High uncertainty in individual technologies and no standardization	High uncertainty in individual technologies but some standardization	Well established technologies available, with rising popularity	Standardized technologies with some market diffusion	Standardized and widely diffused in the market
Smart city engagement	Developing visions for smart city related use cases with the platform	Offering smart city related solutions on the platform	Marketing smart city solutions and engaging in smart city related issues.	Collaboration with city management	Part of cross sector ecosystem with both the city, and other solution providers.
Market readiness	basic knowledge of platforms spreading	Experimentation with platforms	Potentials of platforms clear	Market widely using platforms	Market optimized for platforms

Figure 18 – Maturity model for IoT platforms in Smart Cities. Adopted from the following maturity models: (Arthur D. Little & Telia, 2017)(Ericsson, 2015)(Gartner, 2016)(European Parliament, 2014)

6.3 Business model analysis

Now that the requirements from the city's perspective has been clarified, as well as the potential for the technological aspects of the platforms has been analysed, the ways in which IoT platforms can create value for Copenhagen will be in focus. This is done by looking at the business model of IoT platforms using the STOF model, and analysing which possibilities there are for improved value creation in each of the four domains. This last part of the analysis will therefore go through each of the four domains, and end with a conclusion of the outcome.

6.3.1 Service Domain

The value created by the company, and consumed by the customer or end users, is what the service domain is focused on. In order for the process to function, and for customer value to be created, the service has to be new or innovative, and to be better than what the competitors has to offer (Bouwman et al, 2008). IoT platforms provide a service, which bundles together functionality that individually might not be completely new, but merged into a platform, provides innovative solutions and thereby creates value. But the experience with the platform also has to be valuable, and this is done by understanding and adapting to the characteristics of the users.

As found in the theory chapter, the main aspects of the service domain are the intended-, delivered- expected-, and perceived value. This following section will look into these aspects, and focus on how the business model can be affected in ways that match the established requirements and market conditions.

Intended value

IoT platforms mainly deal with B2B services, as the platforms are used to create additional products or services. This also means the customers who purchase the platform services might be the decision makers of a company or organisation, whereas the end users can vary from solution developers, project managers or other involved employees. The type of value that is created deals with parameters that are different from consumer products. IoT platforms therefore arguably has to deliver less socio-emotional value, such as the sense of belonging or self-actualisation, whereas instrumental values such as control and privacy has a higher priority.

The market segment, which IoT platforms can focus on in relation to smart cities, is especially large in Copenhagen, as the public sector has a large presence on the market. This is also the opinion of Netplan: *"in Denmark, where the state is very large and they have many physical buildings throughout the country, the potentials of value creation from IoT is large, compared to e.g. a small company with smaller physical presence. The scale is therefore a natural incentive for getting local governments involved in IoT*" (Appendix A2, 43:10).

The market review also revealed a large potential in the IoT market in relation to smart cities, but a number of barriers limits the market growth. An increased focus on both communication of possibilities, as well as collaborative development with city management could be a way of bringing more of the intended value into the actual value creation. CPH solutions lab also believes co-creation is a way of achieving value from IoT solutions: "*We can't develop the systems ourselves, but the companies can't develop solutions that fit our needs perfectly either, so we need to do it together*" (Appendix A1, 41:20).

The value proposition from the Cisco Kinetic for Cities, as described in the state of the art chapter, is to create a smart city framework that improves operational effectiveness, promotes flexibility, creates opportunities and reduces risks (Menon, 2017). This is rather vague, which value propositions tend to be, creating some uncertainty in what the delivered value actually consists of. The strength of the platforms, being highly modifiable and providing many different functionalities in their solutions, can be hard to formulate into clear value propositions, increasing the need for clear communication.

Some platforms have a multisided approach to the market, where they propose partnerships between development experts in various fields, with customers who need specific IoT Solutions. An example of this is the Azure IoT Suite, which has created a network of partners in various fields, including smart cities. The value proposition for the side of the platform which demands the IoT solutions, is to make the development simpler and tailored to their needs, whereas the value proposition for the side providing expert skills, is to reach new customers and expand their businesses (Microsoft, 2017c)(Microsoft, 2017d).

In relation to the services provided on the platform, the trend of separating the services in a number of categories, as Cisco's Kinetic for Cities does, can also specify the intended value, and better match the various needs of the customers. In the case of Copenhagen, they could start with a single IoT solution, and only utilise the "things as a service" option, and later scale up to the "business as a service" category.

Delivered value

The delivered value from IoT platforms to smart cities in general, is dependent on the technological decisions in the platform, as well as the value activities. The IoT platforms are involved in the fourth layer of the architecture stack developed in the state of the art chapter, and this means the capabilities rely on both processing, analysing and providing data for the application layer to access. The delivered value is therefore highly dependent on the capabilities of connecting sensors to the platform, as well as many of the traditional cloud-based activities. Security has also been identified as an important aspect of the delivered value. This is a general challenge in relation to IoT solutions, and needs to be included in the platforms' capabilities. The analysis of the technological- and organisational domains will include more focus on the aspects that affect the delivered value

Expected value

From the customer's side, the hype around the technology can have a big impact. As found in the forecast, high expectations as an effect of hype, has a high possibility of resulting in disappointments when these are not met. Many technological trends in recent time has promised a lot of possibilities and value, but also disrupts the current state of society, to a degree where there might be a lot of insecurity in the success of the technology. CPH solutions lab also see this in relation to IoT platforms: "*combining all our systems into one, where the city can be controlled, is not something we do today, so it will require a large change in our work processes* (Appendix A1, 8:25). These insecurities are important to recognize, as they can impact the value creation. One way of doing this is to extensively analyse what the implementation of the platform requires from the city's perspective, in order to clearly communicate what it will take to achieve the value. The IoT platform providers need to become experts in the field of smart cities, for the platforms to be applicable in a larger scale. CPH Solutions Lab says this is what the collaborations are aimed at: "*they [IoT platforms] need to make tailored solutions for individual cities, and this is what we call public and private innovation"* (Appendix A1, 43:59).

Perceived value

The perceived value might also suffer due to the high expected value as a result of the hype. But since the platforms are presented as frameworks and tools, as Cisco's Kinetic for Cities, the context denotes that the value will require some effort from the city. However, this effort does not seem clear, and it was found that a large barrier for the market adoption of IoT solutions in general, was a lack of knowledge related to the use of the solutions. The IoT platforms therefore need to clearly identify their role. This could be done developing use cases and business cases in collaboration with the city.

When looking at IoT platforms, it is evident that they focus a lot on the value creation made possible through bundling analytical services, with the other capabilities of the IoT platform. Netplan also identify this as a tendency: "*services related to data analytics and solution specific data handling often require massive computation power, and therefore large companies like IBM and Microsoft see big business potentials in these areas*" (Appendix A2, 1:02:50). This bundling of services has potential to increase the value significantly, and is an important element of the platform's capabilities. Strengths in specific service areas, which can be provided in these bundled services can also function as competitive advantages for the individual platform providers.

Lastly, the effort and tariff also has an impact on the perceived value. Especially the requirements for technological knowledge, and the disruptive effects previously mentioned, increases the amount of effort needed to attain value from the platforms. The pricing of the tariffs will be analysed in the financial domain.

6.3.2 Technological domain

As mentioned in the theory chapter, the high complexity in the technological characteristics of the companies providing IoT platforms, makes it difficult to perform an extensive analysis within the scope of this report. But by looking at the key elements of the technologies behind the platforms, the most essential areas can be analysed. These key elements were established both in the state of the art chapter, as well as in the market overview and the forecast. By combining these elements with the requirements from the city, the analysis should be able to identify an optimal way of structuring the technological domain of IoT platforms in Copenhagen.

Platform applications

Firstly, the platform contains a number of applications, through which the users access the functionality of the platform. The applications apply the technical functionality of the platform to the streams of data, to create value for the customers. In many platforms, an essential application is the one with the gateway functionality, linking the platform to the things. This application is then connected with a multitude of other applications, such as the rules engines concerning device and data management, storage applications, ID management and registries, and many others. All these applications can be accessed and managed through the platform interface. But this interface can be accessed in different ways, depending on the end user's context. IoT solution developers might access the interface through their PCs, while city management and operation personnel might use tablets or mobile devices. In most cases, it will only be developers who use the platform management interface, as the IoT solutions often have their own interfaces, through which the end users access the services, but some advanced IoT platforms also have interfaces or dashboards aimed at the end users. In either case, the multitude of users should be considered when providing the platforms.

An important element of the applications in general, is that data security and privacy is an integral aspect. CPH Solutions Lab also identifies this to be essential in relation to city management: "*In the future, privacy is completely essential to have under control. In local governments this might even be more important than on the private market*" (Appendix A1, 12.20). Data security and privacy therefore needs to be available in all aspects of the platform, to be able to meet the requirements of the city.

Vast amounts of data are travelling through the platform, and in some IoT solutions a low latency might be essential, while others are less time sensitive. The latency was found to be highly dependent on the choice of communication technologies, so the platform needs to be able to provide instantaneous access to the data, if this is a requirement from the users.

Service platforms

Some of the technological architecture for managing the platforms can come from external middleware platforms, such as customer billing systems, customer relation management systems, and much more. This will vary from platform to platform, and many of the more established IT companies might not need external service platforms. But service platforms can also concern aspects that make the platform more dynamic. If an IoT platform does not have machine learning capabilities in its arsenal of services, a service from a provider of machine learning could be connected to the IoT platform, and thereby increasing the value creation. Other examples of functionalities like these are databases, artificial intelligence, and block chain. These partnerships or connections to external service platforms can be seen as a form of market collaboration. Here, the IoT platforms needs to be open, in order to combine solutions in ways that matches the needs of the city. They also need to prioritize the research of the market for potential partners. Netplan explains this as a form of agility, which is very important for IoT platforms: "*It is hard, but they [the platforms] need to be open in order to survive. They know this, but it requires a lot of agility to navigate in an environment where technology, suppliers and use is constantly changing*" (Appendix A2, 01:05:28). Agility in the platform, in relation to interoperability with other solutions, also combats the fear of lock-in, that might be present with the decision of selecting one IoT platform over another. Netplan says: "*You become locked-in to the technology, and it can be hard to open up for market competition, and reap the advantages of sharing the need with others, which gives companies incentive to provide the solution cheaper*" (Appendix A2, 1:00:20). The need for partnering with one specific company is also not particularly interesting for the City of Copenhagen, as CPH Solutions Lab explains: "*Whether it is one platform from one provider, or a number of solutions from a variety of providers is not important. Our goal is to solve our problems"* (Appendix A1, 39:40). The agility and openness of the platforms can thereby be an advantage for the IoT platforms. The openness and partnerships will be further analysed in the organisational domain. Additionally, Interoperability is expected to account for 40% of the total value potential for IoT, making this an important element to focus on for the platform providers (Arthur D. Little & Telia, 2017). Cisco also identifies this as one of the main competitive advantages of an IoT platform: "*We believe the platform should be open, both downwards in the value net, by not locking in with a specific sensor system supplier, and upwards with openness to third party applications that use the data from the sensors. This functionality should be provided with open APIs. Other platforms that have interests in specific sensor suppliers, tend to become more closed*." (Appendix A3, 10:10). If the data is shared with and open data platform for the city, additional market potential can be created (COWI, 2016). However, the data handling needs to be done in compliance with regulations from the city, which could include requirements for regional storage as well.

Access network and backbone infrastructure

There need for connectivity and broad band internet access is very large, when providing internet based services, which the IoT platforms does. The platforms therefore could use multiple internet service providers, to secure access if one connection is stopped. Both Cisco and Netplan identify the telecommunication infrastructure as the main driver for the use of IoT in cities, but CPH Solutions Lab has abandoned this idea. This dilemma will be elaborated later in the report. The telecommunication infrastructure only deals with the fundamental internet connection, and a big part of the connectivity also lies in understanding the trends in communication technology protocols, with the purpose of supporting the best of these. This also falls under the category of connectivity management. In a scenario where a sensor has transmitted data in a constrained format such as EXI over a Wi-Fi based local area network, the gateway could pass this message on to the IoT platform thought the network without any processing. The platform therefore needs to support the popular constrained alternatives to the otherwise common and unconstrained standards such as HTTP. In the research of IoT platforms, standards such as MQTT and WebSocket were frequently supported, indicating that this is highly prioritized. This makes sense, as the key functionality of the platforms is to handle these forms of data.

6.3.3 Organizational domain

As mentioned, there are many possibilities that collaboration can create in relation to smart city initiatives through the IoT platforms. CPH Solutions Lab believes that this collaboration needs to happen very early in the development stage of IoT solutions, and says: "*developers in California can't sit and develop something for 6 months, and then come to us afterwards and expect us to purchase it, if we are not involved from the beginning"* (Appendix A1, 41:25). And from the city's perspective, there can be a lot of advantages in collaborating with the IoT platforms, as Netplan explains: "*In relation to immature technology, it can be very good to get partnerships with solution providers who have a good market position and a lot of capabilities*" (Appendix A2, 01:04:30). But the strategies behind these collaborations or partnerships might not be compatible with each other. From the city's perspective, CPH Solutions Lab sais: "*It is not a specific technology or software that is the solution. The solution lies in the dialogue between our needs and the solution developers*" (Appendix A1, 42:45). An IoT platform provider most likely also believes this dialogue is advantageous, but since the revenue streams are dependent on the sales of technological solutions provided by them, they will have a strategy related to gaining market size and increasing use of the platform. This strategy must not be too opportunistic in a way that limits the possibilities of creating an ecosystem of partnerships with other solution providers as well. Rasmus Blom, a partner in Implement Consulting Group, when interviewed for the analysis of Danish companies' use of IoT, by IRIS Group, describes the situation as follows: "*There is an increasing trend for entering the IoT market with large solution providers like IBM, Microsoft and Ericsson, who are making partnerships with smaller solution providers themselves, in order to create solution ecosystems. These large companies know that they can't make the entire IoT solution themselves. But they can become a central partner for clients, and take responsibility for the complete IoT solution, which actually consists of partnerships with many subcontractors*" (IRIS Group, p. 60, 2016). Here, there is talk of an aggregator ecosystem, as opposed to the marketplace ecosystem. This might create some competitive advantages, but could create problems if subcontractors are changed, and the service varies. Having a marketplace ecosystem could in such a scenario create more transparency, and perhaps even increase the market competition, which might affect the technological development positively.

The following segments will describe the relation with some of the main actors in the value net besides the city management:

Creators

Solution developers are also a customer segment for the IoT platforms. They utilize the applications and services on the platform, to develop their IoT solutions, and sell them under their own or the platform's brand. These are the market actors referred to as creators in the market review. But as mentioned in the statement from Rasmus Blom, partnerships with solution providers can be an important asset for the IoT platforms. They can include IoT solutions, which are showing potential in specific use cases or sectors, and through this partnership, become more competitive in these sectors. The partnerships can also create a lot of value for the developers. A conclusion to the IoT market analysis by IRIS Group suggested that Danish creators can compete with the cheap sensors from large international hardware vendors, by focusing on quality hardware and -software, which gives the sensors innovative functionality (IRIS Group, 2016). These capabilities are easier reached, if the developers focus on the innovative aspects of their solutions, and utilize a strong value network through the IoT platforms, to deliver other parts of the capabilities. Having a strong partnership with the creators, can also provide the IoT solutions with a number of tangible use cases for the city to see. Cisco notes this as an important way for the city to justify investments in IoT solutions: "*the solution is to find the correct use cases that can prove the value of the infrastructure investments, in relation to the needs of the city and citizens*" (Appendix A3, 5:40).

Enablers

In relation to partnerships with infrastructure providers, the potential partnerships with internet service providers is not the only possibility. Utility providers also manage central infrastructure elements, and investment in IoT solutions in relation to their infrastructure, can create many possibilities for integrating IoT in the city. Netplan developed an IoT solution for utilities in Frederiksberg municipality, which included covering the entire city with Wi-Fi access points. Wi-Fi was selected due to the compatibility with the devices monitoring the usage of heating and water in the individual households. The access points were installed in the city's lights, which have fibre optic internet connections, and in these access points, so called "outdoor media gateways" were implemented, which makes it possible for future IoT solutions to plug directly into the infrastructure. Netplan says: "*The collaboration with the utility company, where the costs of the infrastructure were shared, was what made it possible in Frederiksberg. Now, IoT solutions are a matter of implementation rather than infrastructure design, which is much cheaper for the city*"

(Appendix A2, 44:00). This statement looks at the investment from the city's perspective, but it is also relevant in relation to the IoT platforms, as they can form tight partnerships with infrastructure providers, and thereby make solutions like the one in Frederiksberg possible in Copenhagen. The partnerships could shift from being supporting, towards more structural partnerships, by merging the utility services with the IoT platform. But structural partnerships might create some mismatch with the needs of the city. CPH Solutions Lab sais: "*We used to want to have the infrastructure first, before IoT could be applied, but this thought has been abandoned. Now it will be in smaller steps*" (Appendix A1, 4:20). So perhaps contributing partnerships are preferred in such situations, making it possible to both provide small scale IoT solutions, but also having the capabilities of scaling the solutions up in collaboration with partners, if this is needed.

6.3.4 Financial domain

All domains of the STOF model are important, but the financial domain in particular can have serious consequences for the business operations, if not handled well. The following four segments will describe how IoT platforms can deal with financial elements.

Investment capital and revenue sources

As the IoT platforms often are provided by large IT corporations, the investment sources are rather substantial. Venture capitalist investing in IoT solutions in Denmark has risen with 30% from 2012-2015, but only 4% from 2015 to 2016. This is primarily large corporations such as GE and Intel Capital (Arthur D. Little & Telia, 2017). The hype might be one of the causes of the limited venture capital investments.

The revenues depend on the amount of usage of the platform. Cities have potential of being large customers, as they cover many activities, and solutions in relation to these activities can be scaled up to the city's size. In comparison with a small company, who is interested in using IoT solutions in their business, but only has a small production facility, the possible revenue is limited compared to the city. The revenues are predominantly subscription based, but some additional services, which might be bundled within the IoT platform, can be transaction-based, based on time usage, or other factors (Forrester, 2016).

Costs

In an IoT platform, that consists of many different capabilities and technical aspects, for each of these aspects, there is the question of either developing and supporting it internally, or outsourcing it. Both variations will establish costs, but as the technical aspects are an integral part of the solution provided by the platform, the technology is often owned and supported by the IoT platform provider itself. Having these technologies internally also provides the opportunity of cost sharing. The same equipment provides many services, and a form of economies of scope can be applied. An example of this is the IoT platform providers who have their own cloud- and data centre equipment and solutions. These will be able to implement functionality such as block chain and serverless, in very cost effective ways. By also providing these services individually, the providers create a form of modularity in their design, and the possibilities of bundling different services together increases, which also can result in cost-sharing benefits.

The technical architecture is source of the highest fixed costs in the IoT platforms, but the platforms will also have costs related to many other aspects, such as power usage, internet connectivity and employee wages. The research and development departments should also be prioritised, since having state of the art technology is what the IoT platforms rely on. This will also involve rather high costs, but can provide substantial competitive advantages.

Some value activities might also cause an increase in costs. An example hereof is the partnership Cisco has established with the City of Copenhagen, in relation to developing IoT solutions in the city. As a part of this partnership, Cisco has agreed to support the Danish IoT market with $100 million, in areas such as IoT start-ups and application development (COWI, 2016).

Risk sources

Risks will be an aspect of any new technological solution, and IoT platforms are no exception. Especially with the uncertainty in standards, the security issues, and the difficulties involved in scaling solutions up after an initial test stage, the risks are not few. The choices in relation to the technical architecture needs to be thoroughly planned, as one solution might create some path dependency. Betting on the wrong technology can therefore become very expensive, if shifting to another requires a large amount of change in the architecture.

Pricing

The pricing varies largely, but as mentioned, it is often in the form of subscriptions rather than single investments. This makes the price more flexible, and can be adjusted to fit the changing needs of the customers. Many platform providers also operate with prices based on usage, also known as transaction-based prices. An example is Microsoft's Azure IoT Suite, where a free version supports 8000 daily messages per device, and the most expensive option costs kr. 31.467 per device monthly, which supports 300 million daily messages per device (Microsoft, 2017e). Having a "freemium" version makes it possible for interested developers to experiment with the platform, which is important as the technologies are in the early stages, and the hype is very high.

The prices also heavily imply the scale of the solutions using the platform, as the number of messages supported in the different options are very high. Additional analytics capabilities and other services of course also includes additional prices. These pay-as-you-go prices increases the agility of the solutions, and makes it possible to test smart city initiatives without having to invest in more than what is needed. Providing the platform based on a flexible pricing is a big advantage, compared to an alternative scenario, where the customer would have to purchase the entire hardware and software solution, instead of using it as a service. CPH Solutions Lab mentions: "*There is a tradition of purchasing equipment, owing and maintaining it entirely within the municipality, and even though the evolution is that we increasingly purchase access to the information, it will probably take a while to be used entirely*" (Appendix A1, 30:10). Netplan identifies this trend to be the common way of procuring technology: "*Generally, the majority of municipalities and regions will purchase as a service from operators, as it is not a key competency of a municipality to be network or platform provider*" (Appendix A2, 59:10). Of course, this type of pricing also has some risks, as Netplan points out: "*If you purchase as a service, you have to have a lot of trust in a supplier, and that the service delivery happens in an agile, proper way, and this is not always the case*" (Appendix A2, 58:20). Figure 19 below illustrates the main findings in the analysis of the business model.

Figure 19 - Summarized findings from the STOF analysis (Author)

6.4 Chapter conclusion

The requirement specification illustrated the complexity involved in IoT solutions for the city of Copenhagen, due to the multitude of end users, as well as the wide variety of challenges faced in the city. In relation to technological functionalities, the majority of the established requirements would not be a problem to fulfil for the current IoT platforms on the market. But a specific focus on the city's- and citizens' needs could be improved, particularly in relation to the potential IoT- and smart city solutions has on the environment.

The forecast indicated that IoT platforms are in the early stages of their life cycle, based on the still-increasing amount of hype they are receiving, and the low maturity level of both the technologies, as well as the smart city engagement. The market review revealed attractive market sizes in the future, and a rising amount of connected devices, which works as an incentive for working towards higher levels of maturity.

When looking at the elements of the business model for an IoT platform, the trends, which many platform providers are showing, fits well with the requirements from Copenhagen. However, there are still aspects, which can be improved, in order to cover more of the needs, and create more value in Copenhagen. It is important to note that business models function as a guideline, and needs to be updated frequently, in order to be relevant. The findings in the analysis are therefore also subject to change in the future, but based on the current market conditions, technological development and city requirements, they provide relevant insights.

In general, there is a barrier in the development of IoT solutions in Copenhagen, due to a lack of positive business cases, that can justify the investment. Cisco describes this dilemma as follows: *"It is often a deadlock situation with IoT solutions, because they should be based on a network- and sensor infrastructure, and this infrastructure does not exist yet. The challenge is that the infrastructure investment should be justified based on profitable business cases for IoT solutions, and at the same time, the business cases need the infrastructure to be justified*" (Appendix A3, 2:30). The solution to this dilemma is to prioritize the research and development of use cases that can carry the infrastructure investments. This can be done by finding solutions that work across city verticals. Cisco also indicates the need to include a focus on the citizens: "*If the city management cannot identify the potential value creation from integrating solutions across the silos of the city, it might be advantageous to take the perspective of the citizens"* (Appendix A3, 8:15). Netplan also supports this approach, and indicates that involvement in this process is important for the IoT platforms: "*involvement in the experiment phase is a way of understanding the needs, which could be an approach to bridging the gap between lacking knowledge and added value*" (Appendix A2, 01:09:45). For an IoT platform to do so in Copenhagen, an important focus is the environmental goals, which the city works towards. These goals are created with the citizens in focus, and are what the technological and environmental committee, who are also in charge of the main IoT developments, are aiming at.

The potential for IoT platforms in relation to smart city and IoT activities in Copenhagen does seem evident for both Copenhagen Solutions Lab, Netplan and Cisco, but they all think it will require some time before becoming a reality. Bo Finnemann from Cisco sais: "*Personally, I think it will take a couple of years for the municipality to mature and invest in the infrastructure based on good use cases*." (Appendix A3, 11:50). CPH Solutions lab believes that the needs of cities vary largely, making it hard to find one specific IoT platforms, that works in all cities. They believe it is too early to tell, if a specific IoT platform can be used for the entire city of Copenhagen, and also focus on the development of profitable business cases for IoT solutions. Netplan believes the maturity is essential, and the multiple roles of the city government can be a barrier for implementing a single IoT platform: "The city of Copenhagen is very large, with many different needs, which can make it impossible to agree on a common platform" (Appendix A2, 1:08:00). However, they continue: *"having one central city management platform is not completely out of the question, but it is a matter of will and skills"* (Appendix A2, 01:06:40), and indicates that there are advantages of going that way: "*It is not financially viable to establish individual IT systems for each department, so having one platform in this relation is a better solution*" (Appendix A2, 01:07:00).

The following chapter will evaluate the findings from the analysis and the rest of the research conducted, as well as critically discuss the outcome.

7. Evaluation and discussion

In the introduction, it was established that there is an incentive for cities, including Copenhagen, to utilize the potential of new technologies, in order to become more efficient and smarter. In this relation, the field of IoT is identified as an integral part of unlocking the value of technology for the cities. A trend in the development in IoT is for IT providers to establish a platform, with the purpose of aiding the development of IoT solutions. Based on this research, the following research question was established:

How can an Internet of Things Platform provider's business model be adjusted to match the needs of the city of Copenhagen?

To answer this question, the research has been focused on three elements: requirements from the city, forecasting the technology, and analysing the business model for IoT platform providers. Firstly, the requirements from the city indicated an interest in the adoption of IoT in general, but a lack of clear use cases, and knowledge of how platforms can be utilized. It was found that the current business model of IoT platforms contain elements that match the needs of Copenhagen, but it also illustrated areas that can be improved. Hereunder, openness, dialogue with the city, and flexibility in both pricing and solutions included on the platform, as elaborated in the analysis conclusion.

7.1 Relevance of the research

In much of the literature consulted in the research for this report, the smart city value creation is often mentioned as a possible use case for IoT solutions. Having it as a main focus for the IoT platforms in this report, can therefore be a complimentary input to the literature on the subject. Furthermore, the use of IoT platforms often focus on development of specific solutions, rather than the ecosystem surrounding the platform, and the possibility of using it as a tool for city management, which makes this report a bit alternative in its approach.

As much of the literature and existing research indicates, there are many opportunities for IoT platforms, but the market is at a stage where serious benefits needs to be clarified. The hype around IoT platforms is reaching the limits, and tangible use cases with solid business cases to back them up, are in high demand. Providing insights into how the market can collaborate and create an ecosystem surrounding the IoT solutions, is highly relevant, and this report can contribute with the considerations made in these areas.

7.2 The research approach

The research had an inductive approach, due to the nature of the technology and business model focus. These elements can be combined and developed in multiple ways, making a strict research approach less ideal. The outcome of the research, based on an inductive approach is to establish a theory. In this research, the theory is that the findings from a combination of requirement specifications, forecasting, and a business model analysis, produces relevant guidelines for the IoT platform providers in relation to smart city activities in Copenhagen. Some relevant elements of inductive research design have been left out, to limit the complexity of the research. An example hereof is the Grounded theory approach, which combines both inductive and deductive elements, in order to have a more detailed strategy for finding the theory (Saunders, 2011). This type of research strategy also heavily relies on empirical data in the very beginning of the research, which did not fit with the approach of this report, since the background research was necessary to understand the subject areas first. Now that the theory has been established, it could be interesting to conduct a second round of research, which had more of a deductive approach, with the purpose of testing the theory. However, with the nature of the subjects in focus, still poses challenges for applying the deductive approach.

7.3 The theoretical framework

The theoretical approach of establishing requirement specifications was selected with the purpose of attaining tangible insights on Copenhagen's needs, as well as an experiment of applying service-development practices in a strategic and analytical project. The specificity normally found in requirement specifications, and the following evaluation of whether or not these requirements are met, was not fully utilized in this report. This was both due to the generalized meso-level focus, and the lack of a service development stage. The functional requirements in particular was affected by not being particularly specific, whereas the more general non-functional requirements fit well with the scope of this report. However, the theoretical approach revealed some valuable guidelines for the IoT platforms' business models to refer to later in the analysis, and in that regard, the theory was useful.

Forecasting the technological potential of IoT platforms in relation to smart cities was a goal for this research, both in relation to justifying the hype related to the topics, for the sake of understanding the development trends, and to see how platforms can evolve to become better in the future. The hype was analysed based on Gartner's hype cycle, which is developed by a company with many resources, but can be subjective and is not particularly scientific. Since hype is a difficult term to quantify, it is not entirely valid to evaluate. The contribution it makes to the research is not nuanced, and can be subjective, but it indicates how the technology has evolved, and how it will look in the future, based on common trends. To attain a more nuanced forecast, the maturity model was selects as a theoretical approach to compliment the hype research. The established maturity model was based on a number of existing models, and used the research of IoT, smart cities, and IoT platforms to quantify the levels of maturity in each focus area. In relation to the research question, the maturity model can be used as a roadmap for achieving more value creation in Copenhagen, as an increased maturity creates better conditions for doing so. In that sense, the maturity theory is useful, and it also creates an overview of the future potential of the technology, which is useful for the forecast. In the early stages of the research, the maturity model was intended as the main element of the analysis, but was superseded by the business model, as the focus changed towards value creation.

By using the business model as a theoretical tool in the analysis, a comprehensive view of the characteristics of an IoT platform could be created. The STOF model includes a focus on the technological architecture, as well as the entire value network, which is preferable in relation to the focus of this report. These factors were also what made the STOF model more appropriate than the Business Model Canvas (BMC). Besides the technology domain, many of the same elements from the building blocks of the BMC are covered in the STOF model, making the two rather similar. In both theories, the amount of information available, highly affects the outcome of the business model analysis. Focusing on a single platform provider might have resulted in a more relevant outcome. This could have been Cisco's platform, as they already have a collaboration with Copenhagen Solutions Lab in relation to IoT and smart city solutions. However, for the sake of maintaining a generalized focus on the IoT platforms, as well as not depending on the input from one solution provider, this was not chosen.

In general, having more than one or two theories applied in a research, can increase the complexity to a level that limits the ability of reaching specific conclusions. The three theories used in the research for this report also does this to some extent, but they are complimentary in the sense that there is a logical need for each of the findings they contribute with.

7.4 Future work

Due to the time frame of the research, as well as for keeping the focus within a manageable scope, delimitations had to be made. Some of the areas that were left out, but could have been particularly relevant, were security and privacy elements of IoT solutions. They were addressed briefly a couple of times, but due to their critical impact on the development of the technologies, an increased focus could have been beneficial for the research. Another element, which has been indicated by numerous sources, as being the key to adopting IoT solutions in the city of Copenhagen, is the feasible business cases. Much of the work done by CPH Solutions Lab in regards to attaining value from technological solutions lies in this area, so a relevant aspect of the research in this report, could also be to understand what exactly the barriers for finding profitable business cases are.

The outcome of this research includes a set of guidelines and suggestions for the IoT platform providers, so a natural next step, could be to discuss these findings with some of the companies behind the IoT platforms, as well as the solution developers, and the city of Copenhagen. This could both adjust the findings based on the new input, and perhaps also help make the ecosystem around the IoT solutions more improved for value creation in Copenhagen.

8. Conclusion

In a time where cities face increasing challenges due to urbanization, the intense evolution of highly-capable technologies proposes relevant and innovative solutions. The fields of smart cities, IoT, and IoT platforms was identified as key elements in this evolution, and were therefore researched in the beginning of this report. This research provided insights in the complexity of the three areas, including key elements determining the evolution of each area. In addition to the research on the state of the art, an overview of the current market conditions, as well as empirical data from the main stakeholders, was developed. The market review and the interviews indicated that IoT- and smart city solutions have a lot of potential on the Danish market, but uncertainty in both investments and capabilities of the technologies, generates some limitations for the value creation. The combination of the initial research phase, and the empirical data gathering, provided the foundation for the analysis to be initiated.

To answer the research question, the needs of the city had to be clearly defined, and relevant theories for doing so were adopted from the field of service development. A set of use cases and an overview of interaction examples were produced, and combined with the information from the previous research, resulted in a set of functional and non-functional requirements, illustrating the city's needs. Due to the general focus of the research, the requirements were not particularly detailed, but included relevant findings, such as the need for environmental sustainability, security and privacy, as well as flexibility in the technological solutions. These findings were relevant, as they create a practical reference point for the business models of IoT platforms to accommodate.

Before matching the business models of IoT platforms with the needs of the city, the usefulness of IoT platforms in the context of Copenhagen needed to be verified. This was done through a technology forecast. A maturity model was developed, based on the researched capabilities of both IoT technologies, platforms, and key elements of smart cities. The model indicates that maturity of IoT platforms is rising, due to the highly capable IT companies providing the platforms, as well as the amount of IoT services supported. Factors, which limits the overall maturity level, includes the technological limitations of IoT solutions, as well as the Danish market conditions, and the platform's low engagement in smart city activities. The maturity model was combined with Gartner's hype cycle, which indicated a high amount of hype related to IoT platforms. The amount of hype is mainly due to uncertainty of the platform's capabilities, indicating they are in the very early stages of both adoption and performance potential. The outcome of the forecast confirms the large future potential of IoT platforms, and the characteristics of the maturity model in particular, illustrates how conditions for value creation can be improved.

The final element of the theoretical framework for the analysis consisted of the STOF business model. The theory allowed for a thorough analysis of the four domains in focus, and indicated key areas of improvement, for IoT platforms to create value in the city of Copenhagen. Among the main findings was the need for engaging in an ecosystem around the solutions, by building partnerships with both developers and city management. Much of the value also lies in the agility and modularity of the services provided on the platform, as well as the technological capabilities supported. A main barrier for adopting IoT and smart city solutions in Copenhagen was found to be the lack of profitable business cases for the solutions, and the partnership- and ecosystem approach to both funding, implementation and development could be a way of overcoming this barrier.

As mentioned in the introduction, Copenhagen is not the only city facing the challenges posed by urbanization. The technological development related to IoT platforms and smart city initiatives is also expanding globally, which is indicated by the global focus of the companies behind the IoT platforms. The specific findings related to value creation in Copenhagen might not be directly applicable in other cities. However, focusing on cities' needs when offering IoT platforms, can play an important role in the adoption of IoT, and improve the way cities apply technological solutions to their challenges.

It can be concluded that some IoT platform provider's business models are well equipped for matching the needs of the city of Copenhagen. However, the business models can benefit from being adjusted in both the service-, technological-, organisational-, and finance domains. Some of the key elements for improving the match with city needs, includes establishing an ecosystem around the services, and providing flexibility in both pricing, technology and services. Furthermore, the platforms might achieve competitive advantages through sector specific capabilities, and a more direct focus on the challenges faced in Copenhagen. The implementation of a single IoT platform, covering the various service domains in Copenhagen, is not expected to be realized in the near future. But the research in this report indicates, that an IoT platform could create substantial value for Copenhagen, and make the city better equipped for overcoming the increasing demands and challenges.

9. References

Alam, M., Nielsen, R. H., & Prasad, N. R. (2013). The evolution of M2M into IoT. *2013 1st International Black Sea Conference on Communications and Networking, BlackSeaCom 2013*, 112–115.

Aoun, C. (2013). *The smart city cornerstone: Urban efficiency*. Published by Schneider electric.

Arthur D. Little & Telia (2017). *Connected Things. New digital ecosystems – unlocking the Growth potential of IoT*. 2017 edition.

ARUP & CEDI (2016). *Growing smart cities in Denmark*. *Digital Technology for Urban Improvement and National Prosperity*. Commissioned by Invest in Denmark, a part of the Ministry of Foreign Affairs of Denmark.

Astestiano, E. & Reggio, G. (2002). Knowledge structuring and representation in requirement specification. *Proceedings of the 14th international conference on Software engineering and knowledge engineering - SEKE '02*.

AWS (2017a). *How the AWS IoT Platform works*. Last accessed: September 27th 2017. Available at: https://aws.amazon.com/iot-platform/how-it-works/

AWS (2017b). *What is Pub/Sub messaging?* Last accessed: September 27th 2017. Available at: https://aws.amazon.com/pub-sub-messaging/

Berander, P. & Andrews, A. (2005). *Requirements Prioritization.* Chapter 4, Engineering and Managing Software Requirements.

Bjørner, T. (2015). *Qualitative Methods for Consumer Research*. 1st edition. Hans Reitzel publishing.

Bosch, J., & Olsson, H. (2017). *Towards Evidence-Based Organizations: Learnings From Embedded Systems, Online Games And Internet of Things*. IEEE Software.

Bouwman, H., De Vos, H. & Haaker, T. (2008). *Mobile Service Innovation and Business Models*. Springer.

Boyle, E. & MacArthur, E. (2013). *User Requirements – three areas to include and one to avoid. Coley Consulting, Information and advice for software testing*.

Chiang, M., & Zhang, T. (2016). Fog and IoT: An overview of research opportunities. *IEEE Internet of Things Journal*, *3*(6), 854-864.

Cho, Y. (2013). Investigating the merge of exploratory and normative technology forecasting methods. In *Technology Management in the IT-Driven Services (PICMET), 2013 Proceedings of PICMET'13:* (pp. 2083-2092). IEEE.

Cisco (2012). Smart city framework: a systematic process for enabling smart+ connected communities. *San Jose, USA: Cisco Internet Business Solutions Group (IBSG)–2012.–11 p*.

Cisco (2017a). *Cisco Kinetic for Cities Data Sheet*. Last accessed: September 26th 2017, Available at: https://www.cisco.com/c/en/us/products/collateral/se/internet-of-things/datasheet-c78-737127.html

Cisco (2017b). *Cisco Kinetic for Cities*. Last accessed: September 28th 2017, Available at: https://www.cisco.com/c/en/us/solutions/industries/smart-connected-communities/kinetic-for-cities.html#~stickynav=1

Cisco (2017c). *Cisco Kinetic for Cities. Manage your city in the palm of your hand*. Last accessed: December 12th 2017. Available at: http://www.infocomcy.com/presentations/2017/1/drakopoulos.pdf

COWI (2016). *Smart City Infrastrukturanalyse*. Københavns Kommune. Slutrapport, version 1.1.

CPH Solutions Lab (2017). *Projects*. Last accessed: October 13th. Available at: http://cphsolutionslab.dk

Dameri, R. P., & Rosenthal-Sabroux, C. (Eds.). (2014). *Smart city: How to create public and economic value with high technology in urban space*. Springer.

Designspark (2015). 11 Internet of Things (IoT) Protocols You Need to Know About.

Dhillon, H. S., Huang, H., & Viswanathan, H. (2017). Wide-area wireless communication challenges for the Internet of Things. *IEEE Communications Magazine*, *55*(2), 168-174.

Dueholm, A. (2017). *NB IoT: Fremtidens netværksstandard*. TDC perspektiv. Last accessed: December 7th 2017. Available at: http://perspektiv.tdc.dk/nb-iot-fremtidens-netvaerksstandard/

Ericsson (2015). *Every. Thing. Connected. A study of the adoption of 'Internet of Things' among Danish companies*. In collaboration with Deloitte and Dansk Industri Digital.

European Parliament (2014). *Mapping Smart Cities in the EU*. Directorate general for internal policies, Policy department A: Economic and Scientific Policy

Firat, A. K., Woon, W. L., & Madnick, S. (2008). *Technological forecasting–A review*. Composite Information Systems Laboratory (CISL), Massachusetts Institute of Technology.

Forrester (2016), *The Forrester Wave™: IoT Software Platforms, Q4 2016. The 11 Providers That Matter And How They Stack Up.*

Gartner (2016). *Maturity Model for the Internet of Things*. (Only table of contents available). Last accessed: December 13th. Available at: https://www.gartner.com/doc/3236023/maturity-model-internet-things

Gartner (2017a). *About Gartner*. Last accessed: December 11th. Available at: https://www.gartner.com/technology/about.jsp

Gartner (2017b). *Gartner Hype Cycle for Emerging Technologies, 2017*. Last accessed: December 11th. Available at: https://blogs.gartner.com/smarterwithgartner/files/2017/08/Emerging-Technology-Hype-Cycle-for-2017_Infographic_R6A.jpg

Gartner (2017c). *Leading the IoT*. Gartner Insights on How to Lead in a Connected World.

Gartner (2017d). *Gartner Says Worldwide Public Cloud Services Market to Grow 18 Percent in 2017*. Newsroom Press Release. Last accessed: November 2nd 2017. Available at: https://www.gartner.com/newsroom/id/3616417

Gerber, A. (2017). *Streamlining the development of your IoT applications by using an IoT platform. A guide to help you understand why you should you use an IoT Platform*. DeveloperWorks, IBM.

Giffinger, R., Fertner, C., Kramar, H., & Meijers, E. (2007). City-ranking of European medium-sized cities. *Cent. Reg. Sci. Vienna UT*, 1-12.

Høeg, N. (2017). *IoT Rammeværk – Oplæg til Den Smarte Vej.* Cisco Systems.

Huang, Y., & Li, G. (2010). Descriptive models for Internet of things. *Proceedings of 2010 International Conference on Intelligent Control and Information Processing, ICICIP 2010*, (PART 2), 483–486.

Hussain, M. I. (2017). Internet of Things: challenges and research opportunities. *CSI transactions on ICT*, *5*(1), 87-95.

IDC (2017). *Worldwide Spending on the Internet of Things Forecast to Reach Nearly $1.4 Trillion in 2021, According to New IDC Spending Guide*. Last accessed: November 23rd 2017. Available at: https://www.idc.com/getdoc.jsp?containerId=prUS42799917

IRIS Group (2016). *Analyse af danske virksomheders brug af Internet of Things*. Udarbejdet for Erhvervsstyrelsen.

Jasper (2017). *Manage connectivity of all your IoT devices*. Last accessed: December 12th 2017. Available at: https://www.jasper.com

Jin, J., Gubbi, J., Marusic, S., & Palaniswami, M. (2014). An information framework for creating a smart city through internet of things. *IEEE Internet of Things Journal*, *1*(2), 112-121.

Khan, R., Khan, S. U., Zaheer, R., & Khan, S. (2012). Future internet: the internet of things architecture, possible applications and key challenges. In *Frontiers of Information Technology (FIT), 2012 10th International Conference on* (pp. 257-260). IEEE.

Kim, J., & Lee, J. W. (2014, March). OpenIoT: An open service framework for the Internet of Things. In *Internet of Things (WF-IoT), 2014 IEEE World Forum on* (pp. 89-93). IEEE.

Kitsos, P., & Zhang, Y. (Eds.). (2008). *RFID security: techniques, protocols and system-on-chip design*. Springer Science & Business Media.

Københavns Kommune (2015). *Fælles København. Vision for 2025*. Købnehavns Kommune, Teknik- og Miljøforvaltningen.

Københavns Kommune (2016a). *KBH2025 Klimaplanen. Roadmap 2017-2020.*

Københavns Kommune (2016b). *Politiske Udvalg*. Last Accessed: October 12th 2017. Available at: http://www.kk.dk/artikel/politiske-udvalg

Li, S., Da Xu, L., & Zhao, S. (2015). The internet of things: a survey. *Information Systems Frontiers*, *17*(2), 243-259.

Linden, A. & Fenn, J. (2003). *Understanding Gartner's Hype Cycles*. Strategic Analysis Report, Gartner Inc.

McGillivray, C. (2016). *The Platform of Platforms in the Internet of Things*. IDC White paper, sponsored by IBM.

Menon, A. (2017). *Announcing Cisco Kinetic for Cities: New name, alignment and evolution for Smart+Connected Digital Platform*. Last accessed: November 26th 2017. Available at: https://blogs.cisco.com/news/announcing-kinetic-for-cities

Microsoft (2016). *Microsoft Azure IoT Reference Architecture*. Microsoft Corporation.

Microsoft (2017a). *Azure and Internet of Things*. Last accessed: September 28th 2017. Available at: https://docs.microsoft.com/en-us/azure/iot-hub/iot-hub-what-is-azure-iot

Microsoft (2017b). *Overview of the Azure IoT Hub service*. Last accessed: September 28th 2017. Available at: https://docs.microsoft.com/en-us/azure/iot-hub/iot-hub-what-is-iot-hub

Microsoft (2017c). *Giv et internet med dine ting et liv med vores IoT-partnere*. Last accessed: December 7th. Available at: https://www.microsoft.com/da-dk/internet-of-things/find-a-partner

Microsoft (2017d). *Bliv en af vores Microsoft IoT-partnere*. Last accessed: December 7th. Available at: https://www.microsoft.com/da-dk/internet-of-things/partners

Microsoft (2017e). *Priser for IoT-hub*. Last accessed: December 8th. Available at: https://azure.microsoft.com/da-dk/pricing/details/iot-hub/

Minoli, D., Sohraby, K., & Occhiogrosso, B. (2017). IoT Considerations, Requirements, and Architectures for Smart Buildings—Energy Optimization and Next-Generation Building Management Systems. *IEEE Internet of Things Journal*, *4*(1), 269-283.

Mikkelsen, M. (2016). *Smart Waste Management in Copenhagen*. Internship report, ICTE 3rd semester, Aalborg University Copenhagen.

MQTT (2014). *Description of MQTT*. Last accesed: December 8th 2017. Available at: http://mqtt.org

Navigant (2017). *Navigant Research Leaderboard: Smart City Suppliers. Assessment of strategy and execution of 16 Smart City Suppliers*. Last accessed: December 7th 2017. Available at: https://www.navigantresearch.com/research/navigant-research-leaderboard-smart-city-suppliers

New York Times (2016). *Hackers Used New Weapons to Disrupt Major Websites Across U.S*. Last accessed: December 12th 2017. Available at: https://www.nytimes.com/2016/10/22/business/internet-problems-attack.html

Nuseibeh, B. & Easterbrook, S. (2000). *Requirement Engineering: a roadmap*. Proceedings of the conference on The future of Software Engineering – ICSE ’00.

Osterwalder, A. & Pigneur, Y. (2010). *Business Model Generation: a handbook for visionaries, game changers, and challengers*. John Wiley & Sons.

Rouse, M (2017). *Infrastructure as a Service (IaaS)*. Techtarget. Last accessed: November 4th 2017. Available at: http://searchcloudcomputing.techtarget.com/definition/Infrastructure-as-a-Service-IaaS

Saunders, M. N. (2011). *Research methods for business students, 5/e*. Pearson Education India.

Sigfox (2017). *Radio Technology Keypoints*. Last accessed: December 7th 2017. Available at: https://www.sigfox.com/en/sigfox-iot-radio-technology

Slocum, M. S., & Lundberg, C. O. (2001). Technology forecasting: from emotional to empirical. *Creativity and Innovation Management*, *10*(2), 139-152.

Sommerville, I. (2010). *Software Engineering*. Ninth edition. Pearson Education, Inc.

Stoltze, L. (2016). *Hvilke frekvenser bliver brugt til 2G, 3G og 4G?* Bredbåndsmatch.dk. Last accessed: December 7th 2017. Available at: http://www.bredbaandsmatch.dk/teknik/betegnelser/frekvenser/

Synergy Research (2017). *The Leading Cloud Providers Continue to Run Away with the Market*. Last accessed: October 7th 2017. Available at: https://www.srgresearch.com/articles/leading-cloud-providers-continue-run-away-market

The Scottish Government (2014). *Smart Cities Maturity Model and Self-Assessment Tool: Guidance Note for Completion of Self-Assessment Tool*. In collaboration with Scottish Cities Alliance and Urban Tide.

Tisljareo, D. (2016). *IoT Teknologien og den Digitale Transformation*. Ericsson presentation.

Tweneboah-Koduah, S. (2015). *Internet of Things (IoT).* PowerPoint slides. Course: Communication and Broadcast Networks, lecture 6. Aalborg University Copenhagen.

UN, Ericsson & ITU (2015). *information and communication technology for urban climate action.*

Van Lente, H., Spitters, C., & Peine, A. (2013). Comparing technological hype cycles: Towards a theory. *Technological Forecasting and Social Change*, *80*(8), 1615-1628.

Van Steenbergen, M., Bos, R., Brinkkemper, S., Van De Weerd, I., & Bekkers, W. (2010). The design of focus area maturity models. *Global perspectives on design science research*, 317-332.

Vasters, C. (2014). *"Service Assisted Communication" for connected devices*. Last accessed: September 28th 2017. Available at: https://blogs.msdn.microsoft.com/clemensv/2014/02/09/service-assisted-communication-for-connected-devices/

Vermesan, O., Friess, P., Guillemin, P., Giaffreda, R., Grindvoll, H., Eisenhauer, M., ... & Tragos, E. Z. (2015). Internet of Things beyond the Hype: Research, innovation and deployment. *IERC Cluster SRIA*.

W3C (2014). *Efficient Interchange.* Last accessed: November 7th 2017. Available at: https://www.w3.org/standards/xml/exi

Wang, M., Fan, C., Wen, Z., Li, S., & Liu, J. (2011). Implementation of internet of things oriented data sharing platform based on restful web service. In *Wireless Communications, Networking and Mobile Computing (WiCOM), 2011 7th International Conference on* (pp. 1-4). IEEE.

Websocket (2017). *About HTML5 WebSocket*. Last accessed: December 8th 2017. Available at: https://www.websocket.org/aboutwebsocket.html

Windekilde, I. (2015). *Technology forecasting and market trends*. PowerPoint slides. Course: Entrepreneurship, Innovation and Business Models, lecture 1. Aalborg University Copenhagen.

Windekilde, I. (2016). *Maturity models*. PowerPoint slides. Course: Green ICT, lecture 8. Aalborg University Copenhagen.

World Bank Group (2017). *Internet of Things, The New Government to Business Platform. A Review of Opportunities, Practives, and Challenges*. Washington, DC 20433.

Yan, L., Zhang, Y., Yang, L. T. & Ning, H. (2008), *The internet of Things: From RFID to Next-generation Pervasive Networked Systems.* Auerbach Publications.

Yaqoob, I., Ahmed, E., Hashem, I. A. T., Ahmed, A. I. A., Gani, A., Imran, M., & Guizani, M. (2017). Internet of things architecture: Recent advances, taxonomy, requirements, and open challenges. *IEEE wireless communications*, *24*(3), 10-16.

10. Appendix

Appendix A - Interviews

Appendix A1

Interview with Sune Fredskild from CPH Solutions Lab. Please see the digital appendix for a sound file containing a recording of the interview.

Appendix A2

Interview with Morten Kjeldgaard from Netplan. Please see the digital appendix for a sound file containing a recording of the interview.

Appendix A3

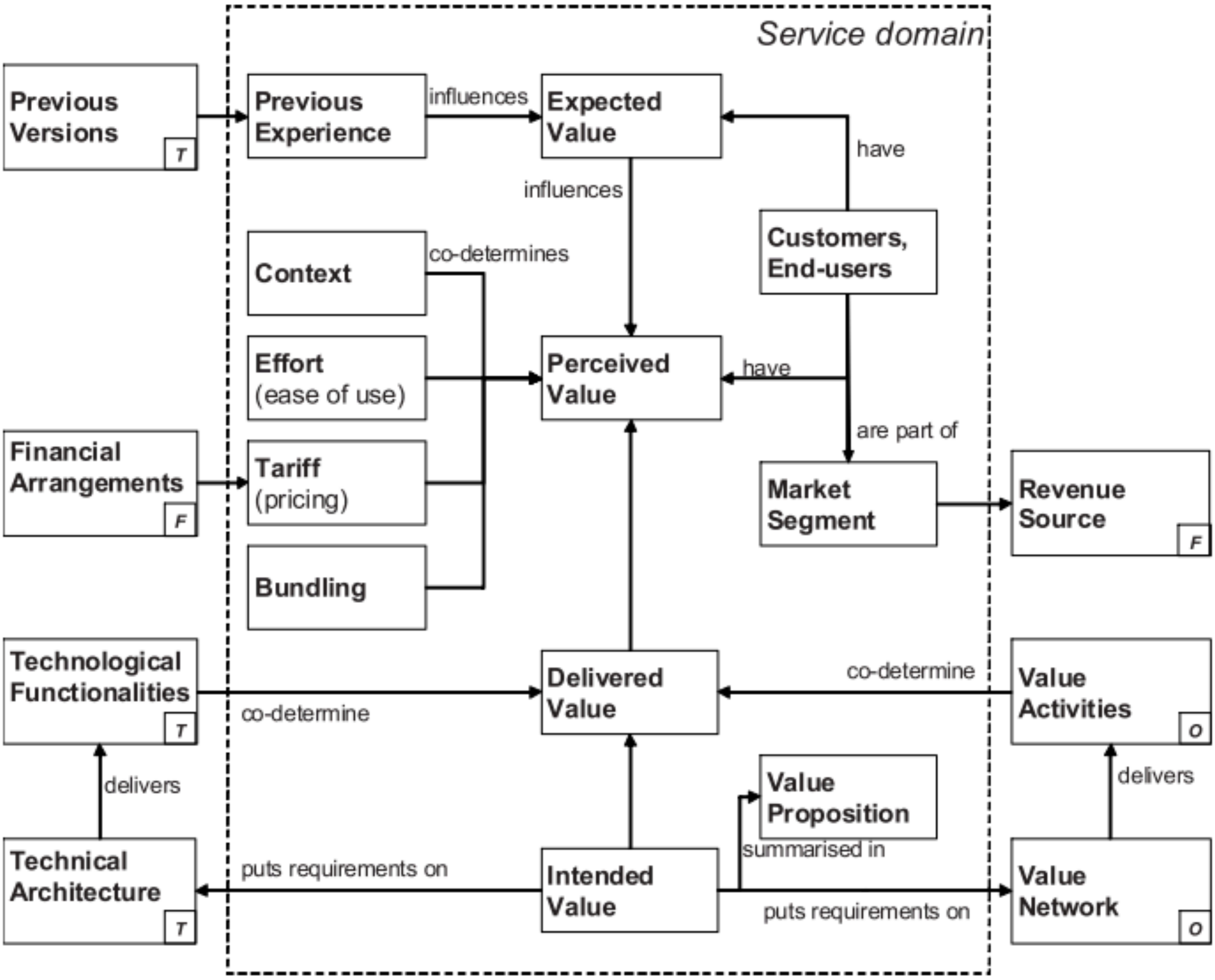
Interview with Bo Finnemann from Cisco. Please see the digital appendix for a sound file containing a recording of the interview.

Appendix B – STOF domain figures

Detailed figures for each of the four domains of the STOF business model, as illustrated by Bouwman et. al (2008):

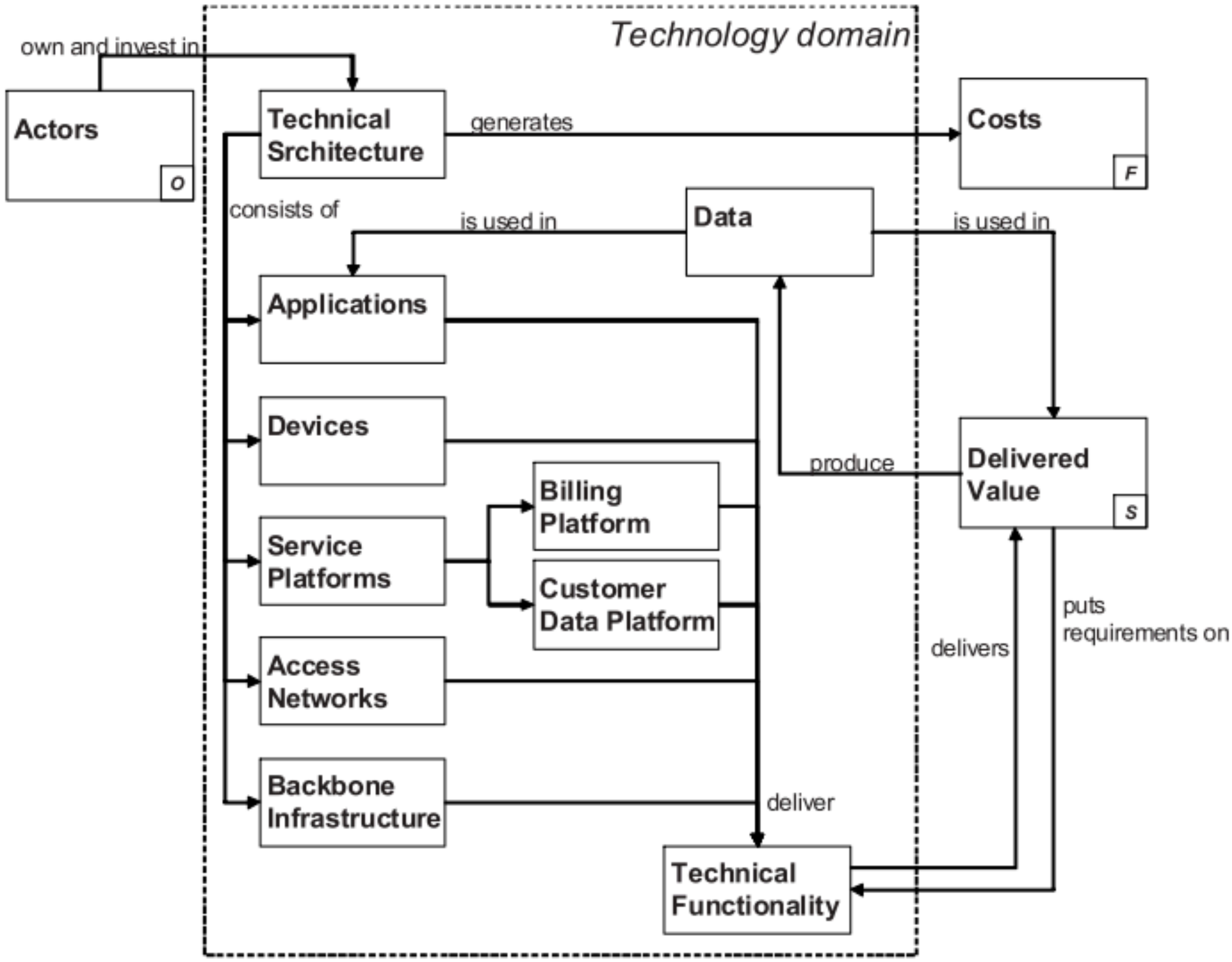
Appendix B1

The Service domain



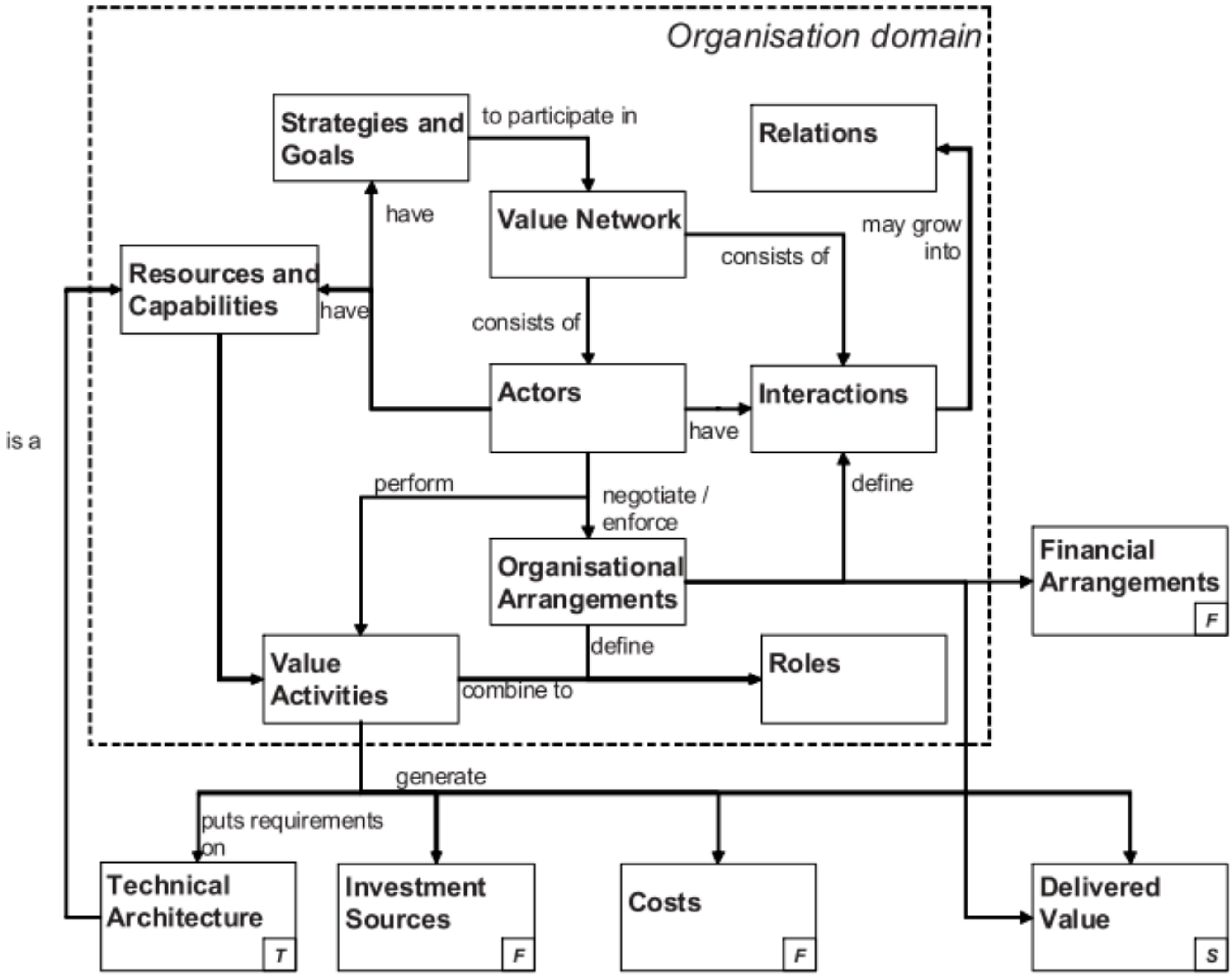
Appendix B2

The technology domain



Appendix B3

The organisational domain



Appendix B4

The finance domain