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Platform infrastructure as a driver of smart city development

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Abstract

There has been a trend in city development for a little under a decade for cities to become “smart cities”, where recent innovations in technology such as big data processing, IoT, and AI are intended to transform the way cities work to become more efficient, more pleasant to live in, and have a better management of natural and human resources. As many cities rush to reap the benefits of this modern development, the need to discuss the possible consequences of this transformation of cities through technology, and how to implement the technology for it to have the desired effects has been pointed out in research surrounding smart cities. This thesis looks at whether applying a platform architecture to the infrastructure of cities can be beneficial when developing a city into a smart city, and if so, how.

Information infrastructure theory and platform studies form the theoretical basis of the thesis; the former is a theoretical framework for large, complex information systems and the latter is the study of IT platforms such as Facebook, Google, and eBay. In addition, the cases of three companies working with smart city projects, as well as Oslo, the capital city of Norway with aspirations to become a smart city, has been studied through interviews and document analysis. The main conclusions are that firstly, a focus on the development of infrastructure is important in a city that wants to become smart because the infrastructure needs to be able to build up under the smart initiatives of the city. Secondly, that using a platform architecture on the infrastructure of a city can make the infrastructure more generative. Thirdly, that developing the infrastructure to be generative can help support innovation, and can answer some of the challenges that have been pointed out in smart city development in recent research.

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Chapter 1 Introduction

The vision of the smart cities of the future is amazing. New technologies and phenomena like the Internet of Things, big data and artificial intelligence are thought to completely change the way in which we live our daily lives. Smart homes will automatically make your coffee and wash your clothes in addition to producing clean energy through solar panels. Self-driving cars are going to take us where we need to go, fuelled by environmentally friendly energy sources like electricity and hydrogen. Artificial intelligence and big data analysis will create a more efficient and adaptable public transport system. Insights from vast data sources will allow businesses to give us services that are perfectly tailored to our needs and wishes. Pollution will be significantly reduced by smarter usage of resources and energy saving technologies. The list of the fantastic benefits and opportunities that technology is going to give us goes on and on.

However, together with all of the wonderful possibilities that these new technologies offer us, there is also a host of challenges and issues that arise. How will the privacy of citizens be guarded in a future where everything is measured and registered? Will everyone get the benefits of these technological advances, or are they limited to those with the resources or knowledge to use them? Who owns the data about citizens that is generated, and what can one do with this data? In addition to questions regarding privacy, equality, and ethics, there are also more practical questions. City governments need to know how they should work to make their city a smart city. They need to think about which parts of the city they should develop, and what can be left to private companies. The corporations and organisations that develop the services, systems and projects that comprise the smart city needs to know how best to introduce these potentially radical changes to a city that has often existed for a long time, and how to change routines and processes in the city to work with the modern technology that can make life easier.

1.1 Motivation

Smart cities are being developed everywhere in the world. Research interest in the area has existed since the early 90's but has not gained substantial momentum until 2010 (Cocchia, 2014). Much of the research that has been done has either produced attempts at defining what a smart city is, or critique against the term and/or its contents. Other research has studied cases of existing smart cities and identified issues and challenges with developing smart cities. A more detailed examination of the existing research can be found in chapter 2.

As the number of projects labelled as smart city projects increases across the world, it is important to discuss how cities should work to become smart, which areas to focus on, what the goals of becoming smart are, and even what is meant by the term "smart city". According to several researchers, there is a lack of research surrounding smart cities, that can take these discussions (Hollands, 2008; Nam & Pardo, 2011; Neirotti, De Marco, Cagliano, Mangano, & Scorrano, 2014)

A large degree of the critique against smart cities, and several of the cities labelling themselves as such, is that there has been too much focus on the merits of new technology and what it can do, and a tendency to use smart city as a positive buzz-word to label a city as future-leaning and forward-thinking (Hollands, 2008; Nam & Pardo, 2011; Neirotti et al., 2014). Another portion of the critique has pointed at the way in which smart cities are governed, and a lack of a clear plan for development of a city as smart, as well as a tendency to focus only on certain areas of city development, rather than governing the city as a whole to be smart in all areas (Cocchia, 2014; Neirotti et al., 2014). Much of the critique points to a tendency of using the term smart city as a self-congratulatory term, and that cities and organisations hastily engage in the future of cities, while a clear plan, definition, and vision are in many cases lacking.

As a response to some of the critique this thesis seeks to look at which challenges exist with smart city development today, and through real-life cases as well as theory suggest some ways in which these issues can be mitigated. The goal is to take a look at smart cities beyond the futuristic vision of the possibilities modern technology can give, and look at how existing cities with an existing mix of people, infrastructure, and usage patterns can be governed to make the city of today ready for the possibilities in the smart city of the future.

1.2 Research question

To be able to explore the topics listed in the previous paragraphs, I will throughout this thesis work towards an answer to the following question: *how can knowledge from research on platforms be applied to the development of smart cities.*

Modern society builds on infrastructure. Whether it is for electricity, transport, water, sewage, telecommunications or the internet, large, complex infrastructures support most activities humans today undertake throughout their day. This is true for the cities of today, and this will also be true of the smart cities of tomorrow. Because infrastructure underlies almost everything that happens in a city, it is important that the infrastructure of modern cities is built to support the new services and technologies that will permeate smart cities.

As a starting point for this discussion, I am going to look at smart cities and their infrastructure through the lens of information infrastructure theory, and consider whether the perspective and concepts from that theoretical field can be applied to answer some of the challenges facing smart city development. In addition to this, research into platforms has increased in the later years (Plantin, Lagoze, Edwards, & Sandvig, 2016), and has given insight into the massive success of large platforms like Facebook and Google. Viewing platforms as an architecture that can be applied to any information infrastructure, I want to examine whether knowledge from the area of platform research can be applied to the development of smart cities to mitigate the challenges that are identified in chapter 2.

1.3 Outline

The following is a short summary of what can be found in the different chapters of this thesis, to serve as a guide to the reader, and give a quick overview of the contents of the thesis. Because of the nature of the data collection and analysis where the two have influenced one another to the point where it makes more sense to describe them in unison, this thesis does not follow the traditional chapter division of first presenting the data before analysing it and then discussing the results. The data is introduced in chapter 5, followed by chapters 6 to 9 which are thematic chapters where both data analysis and discussion is presented.

Chapter 1 Introduction is the introduction you are reading right now, where I am introducing the context of the thesis and the motivation for the research, before presenting the research question that will be examined in the thesis.

Chapter 2 Review of smart city literature contains a literature review of the current research on smart cities. Here I go through the general findings regarding smart cities, choose a definition of smart city to use in the thesis, and introduce some challenges that have been identified with how smart cities are developed today.

Chapter 3 Theory introduces the theoretical framework for the thesis. This is information infrastructure theory and platform theory, including important concepts from these fields that will be discussed in the thesis.

Chapter 4 Methodology is a description of the methodology of the thesis. Here, research paradigm, methodology, and methods are described, as well as my data collection and analysis.

Chapter 5 Case descriptions comprises an introduction of the studied cases where I present Oslo and the three organisations, and argue for their relevance as cases in the thesis.

Chapter 6 Oslo's smart city challenges is the chapter where I begin the analysis and discussion by going through some of the smart city challenges identified in chapter 2, and looking at whether they exist in Oslo and are perceived by the studied organisations.

Chapter 7 The role of infrastructure in city development consists of a discussion on infrastructure where I argue that infrastructure development is important for city development, that governments have the ability to influence infrastructure development, and discuss which traits are needed in smart city infrastructure.

Chapter 8 Developing smart city infrastructure as platforms is a discussion on platforms. I argue that, in general, infrastructures can be developed to become platforms and discuss why this can be positive for smart city development. I then discuss what is needed for platform development in infrastructure before looking at theoretical benefits this can provide in cities, and also benefits for the studied cases.

Chapter 9 Developing platforms in smart cities is the last chapter of discussion and analysis, where I look at how infrastructure owners and legislators can go about developing the infrastructure they administrate and maintain into platforms. I also discuss challenges that can arise when developing platforms.

Chapter 10 Conclusion and future research consists of the conclusion, where I sum up the findings and point at some possible topics for future research to further the inquiry started in this thesis.

Chapter 2 Review of smart city literature

The term smart city emerged in academic articles in the last half of the 1990's but did not gain substantial mention until around 2010 (Cocchia, 2014). As the number of projects labelled as smart city projects increases across the world, it is important to discuss how cities should work to become smart, which areas to focus on, what the goals of becoming smart are, and even what is meant by the term "smart city".

Together with the rising popularity for cities to label themselves as smart, there has also been an increase in smart city research, where some problems with both smart cities as a concept and the term itself have emerged. In this section, I will first go through some proposed definitions of what a smart city is, and select the definition I am going to use in this thesis. This will include a discussion of some of the criticism of the term "smart city" and its usage. I will then go through some problems with the concept of smart cities that has been discussed in recent research, as well as some critique of how cities that want to become smart are planning and performing their development.

2.1 What is a smart city?

2.1.1 Smart city as a fuzzy concept

According to several researchers, there is little to no consistent usage of the term smart city between those who use it to label cities and initiatives as smart. There is also a lack of academic research in the field (Hollands, 2008; Nam & Pardo, 2011; Neirotti et al., 2014). Hollands (2008) criticises how different cities use the term to label a large range of different initiatives, from more efficient transportation systems, through attracting technological businesses, to green initiatives to reduce pollution and improve waste handling. The article problematizes the usage of the term for initiatives that it can be argued are in conflict with each other (e.g. economic growth and reducing environmental footprint) and also what Hollands calls a self-congratulatory tendency, "what city does not want to be smart or intelligent?" (Hollands, 2008, p. 304).

Nam and Pardo (2011) begin their article by pointing to many positive effects from smart city initiatives, describing how different cities has experienced economic growth and solutions to problems with ageing infrastructure and traffic congestion. However, they too problematize the lack of a clear definition in the usage of the term. According to these researchers, the smart city concept builds on several related concepts, across three dimensions of technology, people and community. These concepts, such as *digital city, intelligent city, creative city, learning city, wired city* and several more (see Nam and Pardo (2011, p. 284) for their list), are not clearly defined, the lines between them are blurred, and they are interdependent on each other. Because the concept of smart city builds on several of these related concepts, and different ones depending on whom you ask, a shared definition of what a smart city is, is hard to pin down.

Both Cocchia (2014) and Nam and Pardo (2011) claims that much of the confusion with the definition of the term stems from the unclear meaning of the word "Smart". Nam and Pardo (2011) states that "Smart" has replaced "Intelligent" because the latter has elitist connotations. They also point out that "Smart" has different meanings with regard to city planning and technology. In city planning, smart solutions are forward-thinking effective solutions, while smart technology is technology that emulates intelligence. Cocchia (2014) also identifies smart city as a "fuzzy concept", that is used in inconsistent ways by cities that label themselves as smart.

2.1.2 Possible definitions

I will now present how I define what a smart city is in the context of this thesis, based on the above literature. As was established in the previous section, the exact definition of what a smart city is has yet to be established, and there are several possibilities. Cocchia (2014) identifies nine different definitions in her literature analysis. These nine definitions are much quoted in the current body of literature surrounding smart cities. Seven of these contain an emphasis on the human element of smart cities in addition to the technological aspect, while four have an additional emphasis on the environment.

Cocchia (2014) notes that there seems to be little emphasis on the environmental effect of smart cities in academia, while cities labelling themselves as smart place a large emphasis on this in their projects. Early use of the term "smart city" seems to denote initiatives and projects that aim to improve the quality of life in urban areas, but this is problematic as almost any project can be placed into this definition (Cocchia, 2014). Later it seems like there is a convergence on the fact that technology needs to play a part in a project for it to be labelled "Smart". Taking into account the three dimensions Neirotti et al. (2014) identifies, technology, people and community, it seems the definition should contain both technology and people. Consequently, a positive environmental effect is one of the things that can be achieved with smart city projects, while that does not necessarily have to be the goal, and thus, environmental concerns need not be a part of the definition.

Of the nine definitions listed by Cocchia (2014), some of them are not relevant to this thesis because they place too large an emphasis on technology and little to no focus on the human side of smart cities. Of the remaining definitions, the author notes that some of them are becoming standard definitions through being the most cited ones. Of these, the definition made by Caragliu, Del Bo, and Nijkamp (2011) is the one that I find to satisfy best the criteria of including a focus on both people and technology, and that defines which outcomes are necessary for a project or city to be labelled smart. It is also a definition that explains what is meant with the adjective "smart" in relation to cities, which has been lacking in the usage of the term as described above. This also seems to be the most cited of the ones listed by Cocchia (2014).

2.1.3 Chosen definition

> *We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.*
>
> Caragliu et al. (2011, p. 70)

Even though the definition states that it is a definition for when a city is smart, I will also use this definition for discussing whether a project or product is smart, by looking at whether the project involves investment in human or social capital or infrastructure, and whether it seeks to or has led to the outcomes listed in the definition. Building on the critique and thoughts from Cocchia (2014) and Nam and Pardo (2011), an important aspect of a definition of smart cities is that it should both delineate what can be considered a smart city or a smart city initiative, while also not being limited to high technological solutions and implementations, and taking human capital into account. The definition from Caragliu et al. (2011) does this by specifying that both human and social capital, as well as ICT and traditional infrastructure, are important parts of a smart city. While participatory governance is mentioned in the definition and can be an important and interesting topic when discussing smart cities, it is outside the scope of this thesis, so I will not use nor discuss this part of the definition any further going forward.

While Caragliu et al. (2011) defines "smart" in relation to cities and clarifies what the adjective means in relation to cities, I am going to use the adjective to describe technology and city planning as well. When used in these contexts, the definitions of smart will be the ones described by Nam and Pardo (2011), as mentioned earlier in this section. This means that smart technology is technology that emulates intelligence, while smart city planning denotes modernity and effectiveness.

2.2 Smart city challenges

As well as the critique against the fuzzy definition of what a smart city is, there are other problems with the concept of smart cities, and also challenges related to their development that has been pointed out by researchers. I will go through the criticism in this section and identify major challenges and problems with how smart cities are currently developed. These challenges pertain to social consequences and potential inequality, too much focus on technology, lack of holistic planning, and lack of governance. The challenges related to social consequences and technology will be discussed in section 2.2.1, and the challenges related to a lack of holistic planning and a lack of governance will be discussed in section 2.2.2.

2.2.1 Social consequences and too much focus on technology

Hollands (2008), Nam and Pardo (2011) and Neirotti et al. (2014) are all critical to the amount of focus given to the technological aspect of smart cities, with too little attention given to the impact of smart city initiatives on the community in the cities where they are implemented. Hollands (2008) states on page 315 that

> *"(…) progressive smart cities must seriously start with people and the human capital side of the equation, rather than blindly believing that IT itself can automatically transform and improve cities."*

He points out that in several cases, a sort of class divide has been created in cities where technology plays a prominent role, creating a highly mobile, well-educated creative class, and a large service class who works to provide services and entertainment to the creative class. In these cases, Hollands (2008) states that the smart initiatives often increases the quality of life for the creative class, while a large part of the citizens gets little to no benefit.

2.2.2 Projects controlled by different entities and split focus

Cocchia (2014) describes how most smart city projects and initiatives to date are initialized and controlled by various, separate entities. Consequently, the smart cities that exist are largely a result of bottom-up initiatives where the smart city emerges over time, with little central planning or control. According to the researcher, a top-down governance and plan of the smart city projects are necessary for their success.

Neirotti et al. (2014) have touched upon something similar. They state that there are two separate «streams» of smart city development today. One is focused on the "soft" part of a smart city by which they mean elements which pertain to the education of citizens and promoting entrepreneurship. This stream is largely a result of bottom-up initiatives. The other stream is focused on the "hard" part of a smart city and concerns itself with smart energy grids and transport infrastructure for instance. This stream is largely top-down initiatives controlled by the city authorities. Neirotti et al. (2014) claim that cities tend to follow either the hard stream or the soft one and that a combination is necessary for success in the smart city projects. Both

Neirotti et al. (2014) and Cocchia (2014) are both critical of the fact that too much control of smart city projects is in the hands of separate bodies, and that a clear governance of the projects and initiatives from city, region or national authorities is needed.

All of the aforementioned issues are important and interesting to address when developing and discussing smart cities. However, they pertain to different sides of smart city development, and there probably does not exist one solution that can answer all of them. Because I am exploring how infrastructure development can help the development of smart cities, I will limit my further discussion in this thesis to the challenges that I believe can be mitigated or discussed within the context of infrastructure development and platform architecture. This includes the challenges related to the separate streams of smart city development (Neirotti et al., 2014), the lack of a clear governance from authorities (Cocchia, 2014; Neirotti et al., 2014), and the fractured bottom-up development in many smart cities (Cocchia, 2014). The critique pertaining to the dominating technology focus and potential social inequality will not be discussed to any great extent in this thesis.

2.3 Summary

In the above sections, I have described several challenges with the way the term "smart city" has been used, and how it lacks a clear definition. I have then identified a definition from existing literature, that incorporates what has been described as important elements in research into smart cities, including a focus on both people and technology, and outcomes related to quality of life, sustainability and economic growth. I have also discussed criticisms of the current development of smart cities, such as too much of a focus on technology, a lack of discussion and understanding of social consequences, a current bottom-up development from uncoordinated actors, as well as a lack of a clear plan and governance from authorities in smart cities, and a tendency from authorities to focus either on hard (infrastructure) or soft (values, education) streams of smart city development.

Three of these challenges will be discussed, the exception being the challenges related to social inequality and technology focus, as these are outside of the scope of this thesis. I will now continue introducing the theoretical framework I am going to build on going forward.

Chapter 3 Theory

In this chapter, I will introduce the theoretical framework that will be used in the analysis and discussion in chapter 6 through 9 later. I am going to start by discussing information infrastructure theory, explain the concepts of that theory, and introduce the ones that will be important to this thesis. I will then continue by introducing theory and concepts related to platforms.

3.1 Information Infrastructure Theory

Information infrastructure theory is an information systems theory that emerged to describe large and complex information systems, that could not be adequately described and discussed within existing research theories and frameworks (Hanseth & Lyytinen, 2010). According to Plantin et al. (2016), infrastructure studies emerged from two separate research perspectives. The first one is a historical perspective, in which researchers seek to understand how large technical systems develop over time, to become gradually more interconnected and complex, and how they evolve into infrastructure. The second perspective takes a phenomenological and sociological perspective on complex information systems, looking at how interactions within and between infrastructures happen, and their relation to the societies and contexts they operate in. (Plantin et al., 2016).

Information infrastructures are large IT systems that have evolved to become infrastructure, in the same sense as railroads or electricity grids are infrastructures. Infrastructure is not a thing or an object in and of itself, but systems can become infrastructure in relation to people, organisations and work practices (Star & Ruhleder, 1996). According to Star and Ruhleder (1996), infrastructure is characterised by the following;

It is *embedded* in the sense that infrastructure is a part of other structures. It is hard or impossible to see where the infrastructure ends. It is *transparent*, meaning that it does not need to be prepared or assembled to support tasks, it is readily available. Infrastructure is spatially or temporally stretched in *reach* and/or *scope*, reaching beyond a single event, or one location. The use and practices, the knowledge about infrastructure is *learned as part of membership* in a community. Infrastructure has *links with conventions of practice*, it is both shaped by and shapes conventions in the community it exists in. It is an *embodiment of standards*, as infrastructure changes and shifts to support diverse needs and contexts, its' transparency and connection to other infrastructure is upheld by standards. Infrastructure is not created from scratch but is rather built on an *installed base* of existing systems and infrastructure, inheriting strengths and weaknesses. Lastly, infrastructure is invisible to its' users, and it only *becomes visible upon breakdown*. (Star & Ruhleder, 1996)

Information infrastructures (IIs) are defined by Hanseth and Lyytinen (2010) as a "shared, open, heterogeneous and evolving socio-technical system, consisting of a set of IT capabilities and their user, operations and design communities" (Hanseth & Lyytinen, 2010). Information infrastructures are recursively structured according to the authors of the definition, in that IIs consist of platforms, technologies, people, systems and organisations that are themselves IIs. They can also never be designed in the traditional sense that one or a few designers have control over how the system will turn out. Different entities have control over different parts of the system at different times, and design of the II is almost exclusively done through negotiation and shared agreements. A consequence of this is that it is very hard, if not impossible for an II to be changed in a top-down process where a designer or controller of the II dictates how it should evolve. Rather, change happens as a combination of expected and controlled, and unexpected and uncontrolled agreements on designs, standards and regulations that diffuse throughout the infrastructure (Bygstad & Hanseth, 2010; Hanseth & Bygstad, 2015).

According to the definition by Hanseth and Lyytinen (2010), an II is shared in the sense that it is used and utilised by multiple communities in diverse and sometimes unexpected ways. It is open because the boundaries around it are fuzzy. There is no clear distinction between who can use it and who cannot, and also unclear who can design it and who cannot. In addition, new components can be added to the II and integrate with existing components in ways not intended by the designers of those components. The heterogeneity stems from the sharedness and openness, as diverse components and communities are added to the II over time, utilising different technologies and standards, the heterogeneity will increase. Lastly, they evolve also because of the openness, through the shared control of the system and possibility of "anyone" to add new components to the system, it will evolve with new (both expected and unexpected) functionality over time. (Hanseth & Lyytinen, 2010)

Continuing with the definition, Hanseth and Lyytinen (2010) defines everything that is currently a part of the socio-technical system the "installed base". It is both a constraint because any new component that should be added to the system needs to be compatible with the installed base, but it is also a driver of innovation in an II because components of the installed base can combine and function with each other and new components in unexpected ways. This is related to the concept of generativity that will be described later.

Apple's app store is an example of this unexpected innovation. According to the biography of Steve Jobs, written by Walter Isaacson (2011), Apple originally intended to distribute the iPhone with a limited set of applications, developed by Apple. A community of individual developers, however, managed to circumvent the restrictions Apple had put in place and were able to develop their own native applications to run on the iPhone. Because of this, Apple saw themselves forced to reduce the restrictions, and allow third-party developers access to distribute their own applications through an Apple-controlled application store. The combination of developer interest and capabilities in the iPhones operating system generated third-party applications that were not originally intended by Apple. This consequence, in combination with the existing media store Apple had available through iTunes, generated the vast library of third-party applications that exist in Apple's mobile ecosystem today.

3.1.1 Stability and change

Per the definition of information infrastructures, they consist of an installed base, which all new components need to be made to fit with. Hanseth and Lyytinen (2010) state that when designing an information infrastructure, what is done is not to create and design something new. This is because, as described by Star and Ruhleder (1996), infrastructure is embedded into other infrastructure, and built on an existing installed base. And as described in Hanseth and Bygstad (2015) and Bygstad and Hanseth (2010), top-down control of the development of information infrastructures is hard, if not impossible. Rather, what is done is a cultivation of the installed base, making the new components fit with and interact with the existing base in order to create the wanted and or needed results. This continuous cultivation of the installed base throughout the lifecycle of the II is what makes it evolve.

In information infrastructures, there is a constant tension between stability and change, or between standardisation and flexibility (Hanseth, Monteiro, & Hatling, 1996). This tension emerges from the fact that stability/standardisation and change/flexibility both depend on and contradict each other (Hanseth & Bygstad, 2015). Stability through standardisation facilitates change and flexibility by making it easier to develop new components and standards on which to base these components. At the same time, these added components will inevitably introduce a need for change in the system and its existing components (Hanseth & Bygstad, 2015). Simultaneously, information infrastructures need to change and evolve to survive, but all the components of an II cannot change at the same time if the system is to stay operative. In other words, some components will need to change to make sure other components are stable, while some components will need to stay stable so that others can change (Hanseth & Bygstad, 2015). This means that an information infrastructure needs to have clear and stable standards to make sure the II itself remains stable, while also being so flexible that it can change.

3.1.2 Emergence and generativity

As mentioned earlier in this section, components in an information infrastructure can combine in new and unexpected ways to generate outcomes not intended by the creators of the components, or the components that initiated the outcome. This concept where new properties or functionality appear, seemingly unprompted, is called emergence (Henningson & Hanseth, 2011). The process by which this happens is called generativity (Zittrain, 2006).

In the context of generative technology, Zittrain (2006) writes that the word generative "(…) denotes a technology's overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences", and further "Generativity is a function of a technology's capacity for leverage across a range of tasks, adaptability to a range of different tasks, ease of mastery, and accessibility" (Zittrain, 2006, pp. 1980-1981). A technology's capacity for leverage refers to how the technology enables possible results that would have been hard or impossible to achieve without it. The adaptability is how easily (i) the technology can be applied across a range of different use cases and contexts without being modified, and (ii) how easy it is to modify the technology to apply to other contexts and use cases. Ease of mastery pertains to how easily and fast a new user can adopt the technology as well as how easily they can change it to fit their own needs, and lastly, accessibility refers to how easily potential users can get hold of the technology as well as the information needed to use it. (Zittrain, 2006)

According to Zittrain (2006), generativity emerges in information infrastructures through *generative relationships* and *generative mechanisms*. Generative relationships are broadly described as the discourse between different entities in a system, and how these entities discuss and interpret different artefacts or technologies in different ways. Generative mechanisms are processes in a system in which components with generative properties interact with each other in novel ways, also described as structures of parts working together to create an outcome. Zittrain (2006) argues that a generative information infrastructure should be backed by a generative architecture, which is an architecture that is designed to be generative by having a capacity for leverage, being adaptable, easy to master and accessible.

In information infrastructure theory, emergence has been discussed through Assemblage Theory, which is a complexity theory created by Manuel DeLanda (2006). The application of assemblage theory to information infrastructures has been discussed by Henningson and Hanseth (2011), and it is their article I will base my use of concepts from assemblage theory on. This theory views complex systems as assemblages of components, where one can view the assemblages at different levels, and where components of one assemblage can in themselves be assemblages, much like the way information infrastructures are seen as recursively structured. Assemblage theory explains the concept of emergence in systems by separating the properties of a component, from its capacity to interact with other entities. The former is what defines the component, and what is known about which properties it has. The latter is hidden until exercised, meaning that one cannot know which capacities that lie latent in a component until they emerge in an interaction with another component (Henningson & Hanseth, 2011).

When describing the cases later in the thesis, I will focus on information infrastructure control as well as generativity. Control is an important aspect as it is related to how both the local government in a city as well as the owners of different smart city projects can control the evolution of the information infrastructure they are cultivating, and aspects such as how to control, what to control, and who should control which parts are of interest. The concept of generativity is related to how one can make the city adaptable to change, and open for innovation, while still keeping it stable and predictable for all actors involved

3.2 Platforms

I will now introduce two streams of platform research; platforms as a system architecture, and platforms in a broader market perspective. The definition of and research of platforms as an architecture is what I will mostly base my discussions in this thesis on. However, the market perspective also looks into the mechanisms that have been the drivers of platform development in today's society. I believe these mechanisms to be important to understand as a basis for the discussion of developing infrastructure as platforms because the mechanisms behind the development of platforms in a market environment need to be understood and to some degree replaced or replicated in a monopoly environment, to be able to develop infrastructure into platforms.

As mentioned above, there are two separate streams of platform research, one that focuses on platforms as a technical system architecture, and another that in addition to the architecture focus, looks at the market dynamics a platform system operates in. I am going to describe both of these in the following paragraphs. It is hard to find a shared definition of what a platform is. The term seems to have been used within the realm of information systems in the mid-1990s, as Windows was described as a platform by Microsoft, and as Netscape described their browser, Navigator, as cross-platform (Plantin et al., 2016).

In the field of information systems research, and in the field of media studies, the concept of platform denotes an architecture, as can be seen in, among others Plantin et al. (2016) and Bygstad and D'Silva (2015). This concept of architecture will be described further down. There is another stream of research on platforms, that uses the architectural definition to varying degrees to denote a platform, however this stream is also focused on the market dynamics that relate to platforms, and subsequently do not see platforms as *just* an architecture, but the architecture, as well as the market dynamics and structures that relate to platforms. This stream can be seen in – among others – Tan, Pan, Lu, and Huang (2015) and Tiwana (2013), and will also be discussed further down in this section. I will start by describing the platform architecture, as this is common between the two research streams.

3.2.1 Platforms as a system architecture

Conceptually, a platform consists of three elements; core components that are stable and low in variability, complementary components that are highly variable and unstable, and interfaces between the core and complementary components that enable modularity between them (Plantin et al., 2016). The core components are developed and maintained so as to give support to the functionality of the complementary components. Communication between the two happens through interfaces that are clearly defined, and through which the complementary components can leverage the capabilities of the core components. The main benefits of this architecture are the reusability of functionality from the core components, and the removal of complexity from the complementary components (Plantin et al., 2016).

As an example, take a computer operating system, such as Microsoft's Windows. There is a lot of complexity associated with creating a computer that is useful for any purpose. As computers basically work by sending electrical signals to and from tiny transistors, there needs to be a translation from the electrical signal interface, to an interface that humans can use and understand. There is also a very limited set of things that a computer can do without additional programming, which mostly consists of reading and writing series of binary numbers, and doing basic mathematical operations on these numbers like addition, subtraction and multiplication. To make the computer useful for a purpose such as browsing the web, it needs a program that can utilise the capabilities that are built into the hardware that allows for networking and input and output to and from the user.

However, other kinds of computer usages would benefit from the same networking and input/output (IO) capabilities. Instead of two separate software vendors creating their own hardware for networking and IO, and creating their own software to interface with the different kinds of hardware that exist, operating systems like Windows are created. The operating system abstracts away the differences in interfaces between different kinds of hardware and contains the software needed to make the computer hardware work together to do complex things like networking, receiving input, writing output to a screen or hard drive, etc. The operating system then has interfaces created for different programming languages, that can be utilised by application developers. In this way, a software vendor that wants to create an internet browser can create it to work with the interfaces for Microsoft Windows and can utilise the networking and IO capabilities that are already created, which saves time during development and also removes a lot of complexity from the internet browser application.

Platforms can be viewed as recursively structured and hard to delineate, just like information infrastructures (see the previous section). To exemplify this; in the example of the Windows platform, in my description above, the platform core can be viewed as the combination of hardware and operating system, while the complementary components are the applications running on the operating system. However, hardware platforms exist as well. Going into the nuances of different kinds of hardware would be outside the scope of this introduction to platforms, but in many ways, the hardware components can be seen as a core with interfaces, and the operating system builds on this hardware platform, to create the interfaces to the applications. This means that from the perspective of the software developers, the operating system and hardware is the core platform, while from the perspective of the operating system, the hardware is the core platform.

3.2.2 Technology platforms as market structures

In the view of platforms as an architecture, described above, the three parts that a platform consists of are the core components, the interfaces and the complementary components. The core components are highly stable and with a large degree of complexity. The complementary components are highly unstable and constantly changing, but with a small degree of complexity. The interfaces are well-defined and allow for communication between the two groups of components, allowing complementary components to utilise the capabilities in the core.

Before I start describing the separate stream of research on platforms as a market structure, I have to address a difference in terminology. In this view of platforms, the term platform is analogous to the core components in the architecture view. The combination of the core components, the interfaces and the complementary components is called a platform ecosystem (Tiwana, 2013). Because I will mostly use the architectural focus later in this thesis, I will continue to use the terms of core components, interfaces, complementary components and platform as they relate to the architecture stream of platform research.

In the platform research that has a focus on market dynamics, the owner of a platform is called the sponsor of the platform (Tan et al., 2015). The sponsor has the responsibility and privilege of developing the platform core and creating the interfaces to be used by the complementary components. The sponsor creates and maintains the rules for usage of the platform for the different user groups, and decides who gets access. According to Tan et al. (2015) platforms are two- or multi-sided, which means that at least two, and often several groups of stakeholders gain advantages by being part of the platform.

To continue with the example of Windows that was introduced earlier, the Windows platform can be seen as a multi-sided market. This is because a) hardware manufacturers like Dell and HP can create computers that will be able to run an operating system and software that users want to and need to use, b) software developers are given access to an operating system that users want to use, and that can run on standard hardware, which makes their software available to a large group of potential users, and c) computer users gain the advantage of being able to choose what kind of PC they want to buy, and get a familiar interface regardless of manufacturer, as well as getting a large library of software that they can install.

The sponsor of the platform also gains advantages from the development of the platform; often the platform sponsor earns money in some form by the fact that other stakeholders use the platform. In addition, as the platform grows and becomes harder to compete with, the sponsor will have cemented their hold on the stakeholders (Tiwana, 2013). Microsoft earns money on licensing of windows, and also the revenue that is generated for them when users buy applications, movies, music and other things through the windows store.

3.2.2.1 Network effects and bootstrapping

The benefits the different stakeholders get from being part of the platform (or platform ecosystem in the market platform terminology), differs from platform to platform. However, what is common to these benefits is that they depend on a certain amount of stakeholders before they are useful. To put it in the words of Tiwana (2013):

> *A platform cannot attract app developers unless it has a large base of end-users, and a large base of users is unlikely to join unless a platform has a large variety of apps available that end-users perceive as valuable (Tiwana, 2013, p. 41).*

The author calls this the *chicken-or-egg problem*, the same phenomenon is called *the bootstrapping problem* in information infrastructure literature (Hanseth & Lyytinen, 2010), and I will call it bootstrapping here as well to be consistent.

Another way to put this is that platforms depend on *network effects* to be useful and to grow. Network effects can be both positive and negative. Positive network effects are when each new user on a platform increases the usefulness of the platform for every other user, while negative network effects are the opposite; each new user subtracts from the usefulness for all other users (Tiwana, 2013). Network effects can also be same-sided or cross-sided. Same-sided is when an added user increases the value of the platform for the side of the platform that the user joins (a new user on Facebook increases the usefulness of Facebook to other users, because the possibility of connections they can make is now higher), while cross-sided network effects affect another side of the market than the one the user joins (a new user on the Windows platform means more potential buyers for software vendors) once the number of users on a side increases enough and reaches what is called *critical mass*, the network effects become a self-reinforcing process, where the addition of new developers or users will lead other users and developers to adopt the platform (or in the case of negative network effects, leave the platform) (Tiwana, 2013).

3.2.2.2 Lock-in

The last concept I want to discuss in relation to market platform research is the concept of lock-in. The concept was explained in the section on information infrastructure and denotes the perceived or actual cost that would be incurred by users of a platform (or information infrastructure) if they wanted to leave the platform and potentially move to a competing one. While this is a phenomenon that occurs in information infrastructures and is generally viewed as a bad thing from the perspective of users, it is something that platform sponsors want to occur in their platforms, to keep users from moving to a competitor (Tiwana, 2013).

Tiwana (2013) describes two kinds of lock-in that occurs in platforms. The first one is called *coercive lock-in*, which is a method in which the platform sponsor increases the cost of switching to another platform to keep users on its own platform. This kind of lock-in can according to the author be bypassed by creating gateways to the competing platforms and is usually not effective in the long run. The other kind of lock-in is called *value-driven* lock-in, where the platform sponsor makes the value of the platform so big to its users that it is not appealing for them to move to another platform.

3.2.3 Summary

To summarise, platforms can be viewed either as a system architecture or as a way to structure a system both technically and govern it market-wise. In both these views, the platform consists of a core of stable and complex components, with complementary components with a small degree of complexity, but a high degree of variability, that leverage the capabilities of the core components through interfaces.

When looking at a platform in the context of a competitive market, the concepts of multi-sidedness, network effects and bootstrapping are important; platforms give benefits to multiple groups of stakeholders as a consequence of a lot of users in the different groups. The benefit for one group is dependent on the size of the other group(s), and because of this, none of the groups wants to join unless they perceive that the other group is already large.

Lock-in is also important, as a mechanism for keeping users on the platform. During the rest of this thesis, I will mostly utilise the view of platforms as architecture, and as such, the concepts of core components, interfaces and complementary components are the most important ones introduced in this section, with regards to the rest of the thesis. As I mentioned in the introduction to this section on platforms, I believe it is important to introduce the concepts related to how platforms evolve and grow in a market environment to discuss how these mechanisms can be replicated or replaced in a monopoly environment. The reason I am utilising the platform definition as an architecture and not the definition as a broader market structure is that I believe that infrastructure can be developed into platforms even within the frame of often being monopolies. This entails that the discussion on platforms will mostly be based on the technical architecture of the infrastructure.

Chapter 4 Methodology

This thesis is placed within the field of information system research and is performed as a multiple case study within the interpretive paradigm, using interviews and document analysis as methods for data collection. I will now describe these elements and the reason for my choice of paradigm, methodology and methods. As stated in the introduction, my research question is *how can knowledge from research on platforms be applied to the development of smart cities*, and I will base the discussion on how methodology and methods are fit to answer this question, as well as discuss these things in relation to the interpretive paradigm.

4.1 Research paradigm

Research paradigms are collections of philosophical assumptions that underlie research within that paradigm. The interpretive paradigm is underpinned by the assumptions that one cannot access reality directly, and cannot examine reality objectively. Rather, access to reality is only possible through social constructions such as language, documents and shared meanings among others. In addition, an interpretive researcher acknowledges that the examination of reality is always subjective to the researcher's interpretations, biases and values (Klein & Myers, 1999; Myers, 1997).

This thesis is mostly based on theoretical discussions about how knowledge from information infrastructure studies can be applied to the development of smart cities. However, to increase the understanding of the opportunities and potential problems with developing infrastructure in this way, I want to understand what the ones who develop infrastructure think about it, and how they are developing the infrastructure currently. To put it another way, a theoretical discussion of how cities should be developed does not contribute much to society if the theory does not have relevance to actual challenges, and because of this I want to examine and discover real-world challenges and issues, and look at whether the theory I employ can actually solve these issues. This entails understanding plans, thoughts and wishes that exist within organisations and among individuals, which cannot be examined directly, but rather has to be understood and examined through the descriptions given to me by the people and organisations that are working with them.

4.2 Methodology and methods

Case studies are a way of learning by examples and according to Flyvbjerg (2006), examples are an integral part of the learning process of all humans. It is a way to learn about a phenomenon, structure, or something else in a context-dependent way. Case studies are a good way to gain deep insight and knowledge about an object of study. In the context of information systems research, case studies are well suited to investigate and understand the system that is studied in the context of the organisation or community it exists in (Myers, 1997).

These same reasons are why I believe case studies to be a good fit for this thesis. As discussed above, the thesis has its basis in theoretical discussions on how knowledge from platform research can be applied to the development of smart cities. Further, I discussed the wish to highlight the possibilities and challenges of this theoretical discussion in real-world instances of infrastructure development. Because of this, I believe that doing a case study of multiple cases is a well-suited methodology, as it allows me to understand and highlight possibilities and challenges from different angles of modern smart city development, and use this deeper understanding of a few particular cases to discuss the merits of the theoretical discussion.

This is what Stake (2005) calls a *multiple case study*, or a *collective case study*, as a collection of cases that are interesting to gain knowledge of a broader class of cases. In this instance, this means studying three cases of smart city infrastructure development to gain insight that can hopefully be applied to the broader class of smart city infrastructure in general. The study is also an *embedded case study*, which consists of a main case, with a focus on several *embedded cases* within the main case (Stake, 2005). In this instance, it is the city of Oslo that is the main case, with several infrastructure cases from Oslo that are also studied.

According to Myers (1997), interviews and documentary materials are the primary methods for data collection in case studies. These are also the ones I have used, as the most conveniently available sources for understanding the cases I have studied. Crang and Cook (2007) describes the goal of interviews, from the perspective of ethnography, as getting detailed knowledge and understanding of the contents of people's everyday lives, as well as the context these people live in. Although this is not an ethnographic study, the rationale behind interviews remains mostly the same; it is a way to gain an insight into the perspectives and thoughts from the people working with infrastructure development and to understand the context of the infrastructure from their point of view. Document analysis serves as a form of triangulation, as a way of gathering background information and context from another source than the interviewees.

Triangulation serves two purposes in a case study according to Stake (2005). The first purpose is that collection of data from different sources can allow the researcher to gain more confidence in his or her interpretations of the data if one's interpretations can be backed by several independent sources. Secondly, gathering data from separate sources can allow the researcher to gain different perspectives on the case, because, in the words of Stake (2005, p. 454) "no observations or interpretations are perfectly repeatable".

As I have briefly described the research paradigm, methodology and methods used, I will go on to describe the process of gathering data for the thesis, and the process by which the research question was selected.

4.3 Analysis and data collection

The work in this thesis has been performed as an iterative process between data collection and analysis through theory. Theory has been used to inform the themes to be explored by data collection, and the collected data has been used to identify which theoretical concepts to focus on when continuing with data collection and analysis. I will therefore first do a short overview of how the two have been performed respectively, and then describe the process of data collection and analysis chronologically.

4.3.1 Data collection overview

As previously mentioned, the methods for data collection in this thesis have been interviews and document analysis. In total there are six interviews that have been a basis for this thesis. They have been conducted in two separate rounds, with two interviews conducted during the first round, and four during the second. The two interviews from the first round were not tape-recorded, whereas three of the four from the second round was.

Round one was conducted during the fall of 2016. The first interview was with two representatives from Hafslund Nett – one project manager, and one from the research and development department – and was performed in their offices in Oslo, Norway. The second interview was with one representative from Datek Light Control from upper management, in their offices at Lillestrøm, Norway.

Round two was performed during the spring of 2017. The first interview was a phone interview with a representative from the Norwegian Water Resources and Energy Directorate (NVE), from the energy market and regulation division. The second interview was with Hafslund Nett, and I met with the same representative from the research and development department as last time. The location was the same as round one. The third interview was performed with Datek Light Control, with the same representative from upper management, in the same location as round one. The fourth and last interview was done with representatives from eSmart Systems in their offices in Halden, Norway, where I met with one director and one product specialist.

In addition to the six interviews described above, I did one interview with a representative from a telecom company during the first interview round. However, the telecom company withdrew from the study shortly after, and the interview has not been used in the thesis. I have also tried to get in contact with representatives from Oslo municipality for an interview, but I was not successful in this.

Organisation	Time	Location	Representatives	Audio recorded
Hafslund Nett	November 2016	Oslo, Norway	Project manager, Research and development employee	No
Datek Light Control	November 2016	Lillestrøm, Norway	Upper management representative	No
NVE	February 2017	Phone	Energy market and regulation department representative	No
Hafslund Nett	February 2017	Oslo, Norway	Research and development employee	Yes
Datek Light Control	February 2017	Lillestrøm, Norway	Upper management representative	Yes
eSmart Systems	February 2017	Halden, Norway	Director, Product specialist	Yes

Table 1: List of the interviews that are part of the basis for the thesis

In addition to the conducted interviews, I have used document analysis as a secondary source for all of the organisations listed above. This has consisted of websites, public documents, and documents that have been given to me by representatives from the organisations. There have also been some e-mail exchanges with representatives from eSmart Systems, Hafslund Nett and Datek Light Control to clarify or fill in information from the interviews.

4.3.2 Analysis overview

I have used theory in this thesis as what Giddens (1984) calls *sensitizing devices*, which means that, as stated previously, concepts from theory has been used to inform which topics and themes should be explored through the interviews, and the theoretical concepts has then been used to identify interesting themes when analysing the interviews and documents.

I have looked at smart cities by using information infrastructure theory as a sensitising device, informing which topics to explore within the smart city literature. This has then formed the basis of which themes to explore during the first round of interviews that was described above. This led to that the first round of interviews was used to get an overview of the smart city projects of the organisations that I was in contact with, and the architecture and composition of the systems that these projects were concerned with.

When analysing the interviews from round one by once again using concepts from information infrastructure theory as a lens, the possibility of viewing the infrastructure developed by the studied organisations as platforms emerged. Theory was used in this instance to look at which possibilities and effects could be attained through looking at and developing infrastructure as platforms, and this was used to prepare the second round of interviews, where the themes of developing infrastructure as platforms and related concepts were discussed with representatives from the studied organisations.

In a final round of analysis, the data from the second round of interviews, along with documents, was analysed through the use of information infrastructure theory, platform literature, and smart city literature, to develop the discussion and arguments found in chapters 6 through 9. In the next section, I will go through the process that led to the research question this thesis builds on, before describing the process of the case studies used as empirical background.

4.3.3 Detailed description of data collection and analysis

4.3.3.1 Conduction of literature review

As a first step of defining which research topic to discuss, I conducted a literature review of current research surrounding smart cities, the results of which can be read in the literature review chapter. This was done by searching for the term "smart city" on Google scholar, and as a first step looking at the abstracts of the resulting articles. The articles I deemed interesting were the ones pertaining to smart cities as a concept, and general implementations of smart cities (such as case studies of specific cities), rather than studies or technical analyses of specific smart city projects. The primary findings from this literature review that influenced the further development of the thesis topic was that there are several challenges with how smart cities are developed today, that were reported and found by multiple researchers (see the literature review chapter for a discussion of these issues).

My first reaction to these issues was to try to look at them in the light of information infrastructure theory, as it seemed like several of these issues could be discussed in an easier way because information infrastructure theory was developed to look at complex, socio-technical systems, and has developed the concepts and terminology for discussing these kinds of issues between people and technology. Because of this, several of the identified smart city issues have to a certain degree been discussed in information infrastructure theory. I then identified certain concepts from information infrastructure theory that could potentially be interesting to investigate in relation to smart cities; these concepts were information infrastructure governance, generativity, the tension between stability and change, and path dependency (see the section on information infrastructure in chapter 3 for definition and discussion of these concepts). The next step was to establish contact with organisations developing smart city projects and perform exploratory interviews with them to find out whether the smart city challenges mentioned in the literature I had reviewed could be found in organisations developing smart cities in Norway, and whether the information infrastructure concepts would be interesting to discuss with regards to real-world cases.

4.3.3.2 First round of interviews

At this point, I established contact with two of the organisations that will be introduced in the next chapter, Hafslund Nett and Datek Light Control, as well as a third company, a telecom company, that later withdrew from the study. Contact with Hafslund Nett and Datek Light Control was obtained through acquaintances that had contacts within the organisations, while contact with the telecom company was achieved through personal contacts. The selection of cases was based on the amount of information I believed I would be able to get from them, a selection method that is called *information-oriented selection* by Flyvbjerg (2006). As a basis for selecting these cases, the most important criterion was that the cases needed to be instances of smart city projects. The definition from Caragliu et al. (2011) is what I use as the basis for discussing whether a project can be deemed a smart city project or not:

> "*we believe a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.*"

In addition, I, of course, had to limit myself to the organisations and projects where I would be able to gain access, and an important factor in the selection the cases I ended up with was the fact that I had acquaintances that could provide contacts within the organisations, and "get me in".

All of the three interviews of the first round were performed in a similar fashion; the goal of the interviews was to gain information about the companies themselves, the smart city projects they were working on, and trying to get a deeper understanding of what the projects were, what they were trying to accomplish, and how they were trying to accomplish this. All three of the interviews proceeded in that order; first talking about the company, their structure and the general nature of their business, then moving onto the smart city project I had contacted them on the basis of, and discussing that on a project level, before moving on to technical implementation. The interviews were performed during the fall of 2016, and none of them were audio recorded. All of the interviews were documented by note-taking during the interviews, which were written up shortly after they concluded.

The organisations and the smart city projects of Hafslund Nett and Datek Light Control will be introduced and explained in the next chapter. I will briefly describe why they were selected as cases now, as well as how the interviews were conducted. The telecom company will not be discussed further, as they withdrew from the study shortly after the first interview was conducted. Hafslund Nett was chosen as a case on the basis of their implementation of smart electricity metering systems (AMS) that are currently being implemented all over Norway. The interview with them was performed in the offices of Hafslund Nett in Oslo, and the first interview was performed with two representatives present; a project manager, and a representative from the research and development department in Hafslund Nett. The interview with Datek Light Control was performed in their offices in Lillestrøm, with a representative from upper management. The written up notes from each of the interviews were sent to the respective representatives to allow them to go over facts and interpretations to avoid misunderstandings and errors.

4.3.3.3 Interview analysis and research question formulation

The data gathered from these interviews were analysed and formed the basis for the formulation of a research question to focus on in the thesis. The architecture of the infrastructures of both companies, along with the plans and goals they had for the future development of their systems was analysed through the use of information infrastructure theory. Through applying concepts from this theory to the gathered data, the idea that it could be interesting to look at infrastructures as platforms emerged. This possibility was explored through looking at platform research, and there seemed to be interesting possibilities in looking at how platforms could be utilised in modern infrastructure building. This led to the formulation of the research question: “how can knowledge from research on platforms be applied to the development of smart cities”.

4.3.3.4 Second round of interviews

After this, a second round of interviews was conducted with the purpose of investigating the opportunities in looking at infrastructure as platforms that could exist in and was perceived by the representatives from the studied organisations. Interviews with both Hafslund Nett and Datek Light Control were conducted, as well as with a third company that will also be introduced in the next chapter, eSmart Systems. There was also a phone interview conducted with a representative from the Norwegian Water Resources and Energy directorate (NVE). This interview with NVE was interesting to the case of Hafslund Nett, because NVE is responsible for the deployment of AMS in Norway, and are also the government body responsible for regulating the energy sector in Norway.

In addition to the criteria for case selection described above, two other criteria also became important; the first of these was that the cases should be instances of infrastructure. I used the definition of infrastructure given by Star and Ruhleder (1996) to determine whether or not the discussed cases could be viewed as infrastructures. The reason it was important that the studied organisations needed to develop infrastructure, is that the goal of the second round of interviews was to examine the opportunities of developing infrastructure as platforms. The second new criterion was that the cases should be related to the concept of platforms, either by illustrating how platform architecture can be used on traditional infrastructure or illustrate the properties of platforms in some way. The definition for platforms I used is the one from the architectural stream of platform research, where a platform consists of core components, interfaces and complementary components, described in section 3.2.1.

eSmart Systems were selected in addition to the other two companies because they in many ways make the development of infrastructure into platforms possible. They have created a business model based on building systems on top of other infrastructure, that allows the infrastructure to be connected to by other systems. The full rationale for why they fit as a case can be read in the next chapter.

The second round of interviews was done in a more formal way and performed during the spring of 2017. In this instance I had prepared questions for each of the companies pertaining to their infrastructure and smart city systems, to discuss the possibilities and opportunities they saw in developing them, as well as questions regarding their views on the potential of developing their infrastructure using a platform architecture. All of these interviews were audio recorded, and subsequently transcribed. In addition, notes were taken during the interviews. The locations and representatives from Hafslund Nett and Datek Light Control were the same, with the exception of the project leader from Hafslund Nett, who was not present for the second interview. The interview with eSmart Systems was performed in their offices in Halden, and the representatives were a director and a product specialist.

There were several goals with this second interview round. I wanted to get a deeper knowledge of the infrastructure of the cases, as this had not been the primary object of query during the first round of interviews. Secondly, I wanted to see whether the interviewees viewed their infrastructure and smart city projects as platforms. Thirdly, whether this was a thought the representatives presented themselves, or whether it was introduced by me during the interview, I wanted to examine which possibilities and challenges the interviewees saw with looking at and developing their infrastructure as platforms.

4.3.3.5 Concluding analysis

Analysis of data gathered from all of the interviews forms the basis of the discussion in the following chapters. The theory from chapter 3 will be used to argue for the possibilities of developing infrastructure as platforms and discussing the challenges identified in chapter 2 on a theoretical level. The case studies will be used to illustrate how the theoretical arguments can apply to real-world situations, and to discuss whether the proposed solutions to the challenges from chapter 2 can be applicable in real-world cases.

In addition to the three interviews performed during the second round, I tried to get an interview with a representative from Oslo municipality but was not successful in this. I was in e-mail contact with several representatives from the municipality, but none of them saw themselves as having responsibility for or knowledge about Oslo's smart city development, or infrastructure development. As mentioned previously, Oslo serves as the main case in an embedded case study in this thesis. Oslo is a case of a city with an explicit smart city aspiration, and the three embedded cases are developing parts of the infrastructure in Oslo, which means that their smart city projects are also part of the development of Oslo as a smart city. The description of Oslo is solely based on available public documents and media coverage of the city's smart city project. This kind of documents, in addition to marketing material and presentations, have also been used in the study and description of the other cases of Hafslund Nett, Datek Light Control and eSmart Systems.

4.3.4 Ethical concerns

Here, I will do a brief account of ethical concerns and considerations that have been connected to the work with this thesis.

Firstly, all interviewees have acted as representatives of the organisations they work for, and not as individuals. This means that interviewees have not been asked questions about their personal opinions during the interview, but have rather been asked to answer on behalf of the organisations they represent. If the interviewees have explicitly expressed their personal opinion during any interview, these statements have been disregarded when analysing the data. The representatives have given oral informed consent for their participation in this thesis.

The summaries that were written after the interviews performed in interview round one, as well as the case descriptions found in chapter 5 were all sent to the respective representatives for them to read through, and they were given the opportunity to correct errors or misinterpretations. I received feedback from all the organisations that were a part of interview round one, and two of the companies described in chapter 3 responded to the request for feedback on the case descriptions.

As I have now described how the research for this thesis was performed, I am going to turn to describing the cases that have been studied.

Chapter 5 Case descriptions

In this chapter, I will introduce the cases that I will be using later in the analysis. I will quickly recap the criteria that were used to select these cases, that have been described in more detail above. Firstly, the cases should be instances of smart city projects as per the definition from Caragliu et al. (2011). Secondly, the cases should be instances of infrastructure, in accordance with the definition of infrastructure given by Star and Ruhleder (1996). Thirdly, they should be related to the concept of platforms, as illustrations of platform architecture, or of the properties of platforms. My understanding of platforms follows the definition from the architectural stream of research, where a platform consists of core components, interfaces and complementary components.

5.1 Oslo smart city

Oslo is the capital city of Norway, with 658 390 citizens on the 1. January 2016 (Statistisk Sentralbyrå, 2016). When including the greater Oslo area[1], the population counts 1 546 706 on the same date (Statistisk Sentralbyrå, 2016). The local government structure in Norway consist of two levels, which are called a county municipality, and municipality respectively. The county municipality has the responsibility of planning and developing the larger region it consists of and takes care of public services that operate in a regional context, such as public transport and upper-level and higher education. Municipalities focus on their, smaller, geographical area, and on public services that are limited to their geographical regions, such as nursing homes, lower-level schools, in addition to several other responsibilities.

Oslo is the only county in Norway that consist of just one municipality. Because of this, the city council of Oslo acts as both county municipality council and municipality council. The city, county and municipality all share borders, so the terms Oslo county, Oslo municipality and Oslo city all refer to the same geographic area. However, the official documents and public information

[1] Defined in «Storbymeldingen» (Kommunal- og moderniseringsdepartementet, 2003)

available from Oslo, refer mostly to the development of the municipality, and not the city or county. Because of that, I will mainly use the term municipality rather than city or county when writing about Oslo in the following sections.

5.1.1 Oslo's smart city plans

Every municipality in Norway must develop a plan strategy at least once every election period, that should "cover the municipality's strategic choices with regards to the development of the municipality society. This applies to both long-term land use, the activities of the sectors, and an assessment of the planning needs of the municipality during the election period." (Kommunal- og moderniseringsdepartementet, 2009, ch. 10).

This plan should be developed based on, in addition to the city council's assessment of planning needs, the views and opinions of regional and governmental bodies, as well as neighbouring municipalities (Kommunal- og moderniseringsdepartementet, 2009). The municipalities also have to develop a municipal master plan, on the basis of the plan strategy. This plan should include one community part, which describes how the plan shall be carried out for the next four years or more, as well as an area plan that is a high-level, legally binding plan for how the areas of the municipality should be developed (Kommunal- og moderniseringsdepartementet, 2009).

The plan strategy for Oslo identifies three major themes that should be emphasized in the development and planning of the city during the four years that the plan is valid for; these are "a change of pace in the climate and environment politics, active and economically sustainable municipality and socially sustainable city and equal opportunities" (Oslo Kommune, 2016, p. 9). The plan strategy notes, with regards to the three major themes that "all of the three thematic areas are based on large, cross-sectorial challenges that trigger comprehensive planning needs and demands cooperation across [different sectors]" (Oslo Kommune, 2016, p. 9).

The plan describes two major challenges as the basis for the major themes. These are challenges related to an increase in the population and challenges with cooperation across sectors in the municipality. The population increase challenge is not specifically interesting for this thesis and will not be discussed further. The cooperation challenges are grounded in, according to the plan strategy, that the existing structure of the municipality, with different sectors for different tasks (such as the city council department of finance, or the city council for city development), is not well suited to solve the modern, complex issues that Oslo face, because these issues need cross-functional solutions, that demand cooperation between different areas of expertise.

The theme of Oslo's municipal master plan for the period 2015 – 20130 is "Oslo towards 2030: Smart, safe and green". This plan has its basis in the previous plan strategy that was developed for the years 2011 – 2015 and is thus not grounded in the plan strategy described above. The current city council is working on a revision of the municipal master plan to place more emphasis on environmental issues, and sustainability (Oslo Kommune, 2016). The current plan has three goals for each of the main areas, and each of the goals has more specific focus areas for how to reach the goal.

Several of the goals municipal master plan could be categorised as goals that smart city planners are reaching for, such as *internationally leading environmental city,* and *confidence in getting quality municipal services.* Looking at the goals and focus areas that the city has categorised under "Smart", these can be labelled as what is called the soft stream of smart city development, focusing on education, quality of life, attractiveness to businesses and high-quality public services. Interestingly, the term "smart city"[2] only occurs four times in the municipal master plan, mostly in comparison to the previous municipal master plan, as "smart city" was one of the goals in the 2013 revision.

[2] Norwegian: Smart By

Even though the term "smart city" is not directly mentioned with regards to the plan for the municipality for the next 15 years, the goals and focus areas outlined can in many cases be directly mapped to Caragliu et al.'s (2011) smart city definition, with the exception of participatory governance. The municipal master plan, as well as the plan strategy both also mention the need for investment in infrastructure to reach those goals (Oslo Kommune, 2015, 2016). Representatives from the municipality have spoken about the city's smart city initiative in the press on some occasions. One example is from the magazine Computer World where the newly instated director of technology and innovation discussed Oslo's strategy and plans to become a smart city, where he explains that the initial focus of their smart city projects will be on mobility, environment and health (Joramo, 2016). While trying to get an interview with a representative of the municipality for this thesis, it was also evident that there were different plans and projects related to the smart city concept in Oslo. However, none of the representatives I spoke to had a definitive answer to where the responsibility for this development was.

There is also a portal on the website of Oslo municipality that explains different smart city projects that Oslo is currently engaged in, with a description of Oslo's smart city strategy. Here, they describe smart city as

an urban development vision to improve the lives of the citizens by being open, connected, sustainable and innovative.", stating further that "*Smart application, utilisation and integration of new technology, sectors and services is key to benefit the most important piece of the puzzle: the citizen.* (Oslo Kommune, n.d.-a).

The projects that are currently listed are spread over a range of areas, from infrastructure maintenance to building construction, health care and mobility (Oslo Kommune, n.d.-b). Curiously, this page is only available in English and only linked to from the English version of Oslo municipality's front page. The information is not easily available for someone visiting the standard Norwegian version of the site.

Oslo is also engaged in the European Union's Horizon 2020 project and has, for instance, worked with Toulouse and Sevilla to become a lighthouse city in the project, which aims to build an IT platform for collaboration with citizens.

5.1.2 Oslo's role in the thesis

Oslo is an old city, and as such contains an old and complex installed base. The city depends on and builds on several infrastructures that have developed and grown together with the city through the years. Even though I am applying information infrastructure theory and concepts from there to city development as a whole, it is hard to argue that a city can be viewed as one information infrastructure. It is, for instance, clear that the electricity grid and the road network in Oslo are two separate infrastructures. However, a city can arguably be viewed as a complex, socio-technical network. Oslo is as such not a case of an infrastructure in this thesis, but a case of a city with smart city aspirations, which can be used as a context to discuss the need for developing infrastructure for a city to become smart. Both Hafslund Nett and Datek Light Control operates some of the infrastructures in Oslo, which will be introduced and discussed in the following sections.

To summarise, Oslo has a smart city strategy, that is visible through their English webpage, as well as in the Norwegian media to some degree. It is also evident from reading the plan strategy and municipal master plan of Oslo that the goals and focus areas for the development of the municipality align with what is high-level goals according to Caragliu et al. (2011). As a city with an outspoken goal to become a smart city, it will be used in this thesis as a context to discuss issues related to the overarching development of smart cities, as well as one of the regions in which the other cases that I have studied operate in.

5.2 Datek Light Control

Datek Light Control (DLC) is a subsidiary of Datek Wireless, located in eastern Norway. Datek Wireless is a company specialised in developing custom machine-to-machine systems, or IoT-systems, for customers, using a mix of their own proprietary technology and open source technology. Datek Light Control has developed an outdoors light control solution that is sold as a complete package, with hardware and managed servers delivered by DLC.

5.2.1 System description

The DLC system consists of three main parts according to my source; a backend M2M server that is the main backbone and controller in the system, individual light fixtures or loops of light fixtures that are being controlled, depending on setup, and message gateways and data concentrators in-between that contains fallback-functionality and passes messages between the server and the light fixtures.

The M2M server, as the representative from DLC calls it, is the backbone of the system. It is a Java-based server that was originally created by Datek Wireless and has since been updated with new features as they have started new projects. The servers in DLC's products are generally running on server hardware maintained by Amazon, and located in their data centres in Ireland. During normal operation of the light control system, control messages originate from the server, and it is the authority on schedules and control parameters. Information and status messages from the light fixtures and gateways will also terminate in the server during normal operation.

The gateways or data concentrators sit between the individual lights and the M2M server. Usually, they communicate with the server through telecom networks such as 2G (GPRS) and 3G (UMTS, HSDPA) technologies, but are capable of or adaptable for use with any communication medium that can communicate with the IP interface of the M2M server. The communication between the M2M server and the gateways can also use SMS in case of other network layers being unavailable. The gateway will receive control messages from the M2M server and relay information from the light fixtures back to the server. The gateways will also store copies of the control schemes and parameters used to control the lights they usually communicate with so that they can continue normal operation, even if the link to the server goes down.

The light fixtures can be controlled in two ways; one is the one that is usually used when the DLC system is installed on existing light infrastructure, according to the interviewee. In this mode, the gateways are connected to a relay that is used to switch the electricity on and off in the power line that a series of lights are connected to. There is also an option to install an electricity meter on the line, so that information about electricity usage can be sent back to the server. In the other mode, often used when installing lighting in a place that has not previously had it, or where the light fixtures are being switched out, there is an individual Light Control Unit (LCU) in each light. These units communicate with the gateway over ZigBee, a wireless network technology, in a mesh network topology. This means that each of the LCUs does not necessarily communicate directly with the closest gateway, but can send and receive messages via the other LCUs. The LCUs connect to the light source and can connect to both old technologies such as incandescent bulbs, as well as modern technologies such as LED. The LCU has a relay that can turn the light source on and off, and can be used to dim lights that have an interface for that, such as 0-10v or DALI. Each LCU can also be fitted with extra equipment such as GPS for automatic location, electricity meters or other equipment that could be of use. Both the gateways and the LCUs are equipped with general purpose I/O-ports.

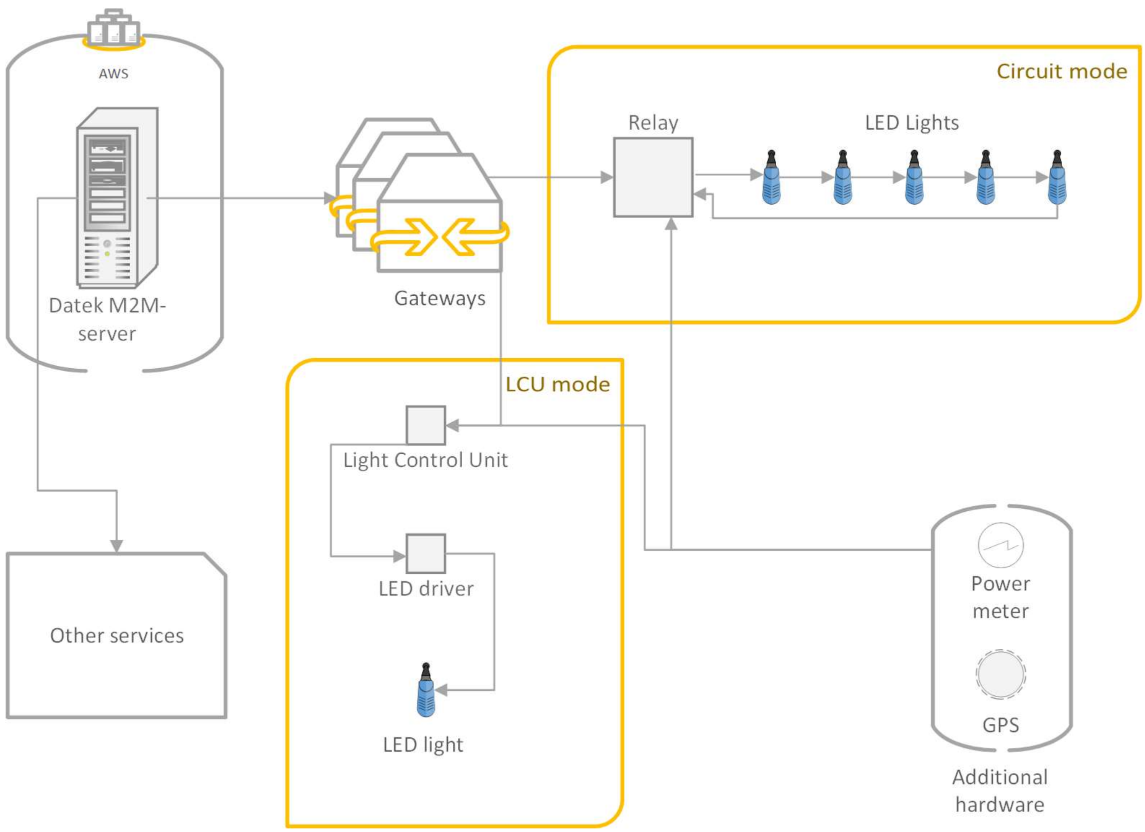

Figure 1: Datek Light Control's light control system

5.2.2 DLC as infrastructure

In the context of this thesis, the case of DLC is interesting because it is a smart city project, involving infrastructure, that has been running for several years. With regards to infrastructure, DLC builds on lighting infrastructure. Lighting has been developed in Oslo over several hundred years, starting with gas lamps that were lit manually by watchmen, and has gradually been developed, added to more places and electrified. When looking at this system through the lens of Star & Ruhleder's (1996) dimensions of infrastructure, it is infrastructure.

It is embedded in other infrastructure, as it is not easy to separate the lighting from the electricity grid that delivers its power, or from the road networks or buildings that are lighted. It is, from the perspective of the users of the areas that are lighted "just there", and turns on and off without them needing to do anything or think about it, and will only be noticed once light is missing, as is as such both transparent and visible upon breakdown. It is both spatially and temporally stretched over large areas and many years, and the way it functions, as well as rules and norms for its usage is learned as part of membership in the communities the lighting exists in. It builds on installed base, using existing electricity cables for power, adding lights to existing roads and buildings, changing light source in existing lamp posts and so on. It has links with conventions of practice, as lighting during dark hours has changed how the streets and areas can be used during this time, as well as adding security. At the same time, people now expect street lights, which they would not do some hundred years ago. Lastly, the lighting infrastructures connection to other infrastructure is governed by and shapes standards, such as building standards for how the poles should be constructed, and standards for the amount of light that is allowed in certain areas, as well as the frequency and voltage of the electricity delivered among other things.

5.2.3 DLC as smart city project

DLC adds "smart" capabilities to the existing lighting infrastructure, of the kind that Nam and Pardo (2011) identifies as technology that emulates intelligence. It does this by adding sensors and actuators to the lighting infrastructure, allowing for automatic and "smart" control based on the environment the lighting is placed in among other things. Introducing DLC in an existing lighting infrastructure has the potential to increase quality of life as well as better the management of natural resources. One of DLC's slogans is, in the words of the interviewed representative *"correct light, at the right place, at the right time"*. The reasoning behind this slogan consists of several points. The first one pertains to conserving energy. If there are no people in an area, there is no reason to power the lights there. The second, and, according to DLC, most important reason is about light pollution.

Citizens living next to a sports field or right next to a lamp post will get a lot of that light into their homes. This can negatively affect the life quality and happiness of the citizens. By using technology to turn on these lights only when necessary, and possibly dim them at times, the way people are affected by this can be reduced. Thirdly, there is a security aspect. People can feel safer when there is light in an area than when it is dark, and police or other security personnel can get easier overview and handling of situations if there is correct lighting there. Related to this is the aspect of well-being. People and citizens can be happier and feel better because of lighting for other reasons than feeling safe.

From this description of Datek Light Control, I have established that it is infrastructure in accordance with Star and Ruhleder's (1996) definition, as all eight of the dimensions they present are there. It is also a smart city product with regards to Caragliu et al.'s (2011) definition, stemming from the fact that DLC's product pertains to infrastructure investments (both in traditional and modern infrastructure), and outcomes related to aspects ranging from preservation of natural resources through energy saving to improved quality of life through appropriate lighting as well as increased safety.

5.3 Hafslund Nett

Hafslund Nett is a subsidiary of Hafslund ASA, a Norwegian holding company who owns several companies that work with electricity production and distribution in different forms. Hafslund Nett is responsible for building and maintaining the regional electricity network in the counties of Oslo, Akershus and Østfold, and is also responsible for the local electricity networks in most of the municipalities in those counties.

5.3.1 System description

The Norwegian electricity network is separated into three parts; the transmission network, the regional distribution network, and the local distribution network. The transmission network is operated by Statnett, a state-owned company. The regional and local distribution networks are owned and operated by several actors in different parts of Norway. This three-part split is described by the representatives I have spoken to as resembling a road network, where the transmission network can be seen as a highway, with several lanes and a high-speed limit, the regional distribution network is like local roads that can be reached through the exits from the highway, and the local distribution grid is like the small road that leads all the way to your home.

The building and operation of electricity networks in Norway are highly regulated by the government, and the governmental body responsible for this is the Norwegian Water Resources and Energy Department (NVE)[3]. There are rules for the quality of the electricity in the grids, the allowed earnings the network operators can have, and the size of the tariffs they take, among other things.

By January 1. 2019, all sites consuming electricity must have new power meters installed, with "smart" capabilities, along with the infrastructure needed for the electricity network operators to utilise the new capabilities, collectively called AMS. The electricity network operators are responsible for deploying the new technology to all consumers. Consequently, Hafslund Nett has the responsibility for installing smart meters for their customers in the municipalities where they operate the local distribution network. Hafslund Nett's implementation of AMS will, according to the interviewee, consist of electricity meters in consumer endpoints, such as homes and businesses, concentrators in transformer sheds, and databases at Hafslund Nett where the data that is collected is stored. The data will then be transferred to Elhub, a central repository for electricity billing and usage data, operated by Statnett.

The meter measures electric current and voltage, in ampere and volt respectively, in and out of the endpoint. The meters also feature a standardised interface that can be used by end users to get meter data. The standard for this interface is specified by NVE and NEK[4], the Norwegian branch of IEEE, and it is called a HAN-port (Home Area Network). The HAN port consists of an RJ45 plug, connected to an M-Bus inside the meter. The HAN-port will transmit predefined data at predefined intervals, and communicates only from the meter and out to reduce the risk of data compromise. The meter also communicates with the concentrator, through radio frequencies. Hafslund Nett's meters are currently not

[3] Norwegian: Norges Vassdrags- og Energidirektorat
[4] Norwegian: Norsk Elektronisk Komité, English: Norwegian Electronic Committee

operating within any standard protocol; they are utilising the ISM frequencies. The meters operate in a mesh network topology, to get data to and from the concentrators. The concentrator collects meter data from all meters within its area and disperses tariff information to them. The concentrator sends data to Hafslund Nett via cellular connections, which means 2G and 3G data connections.

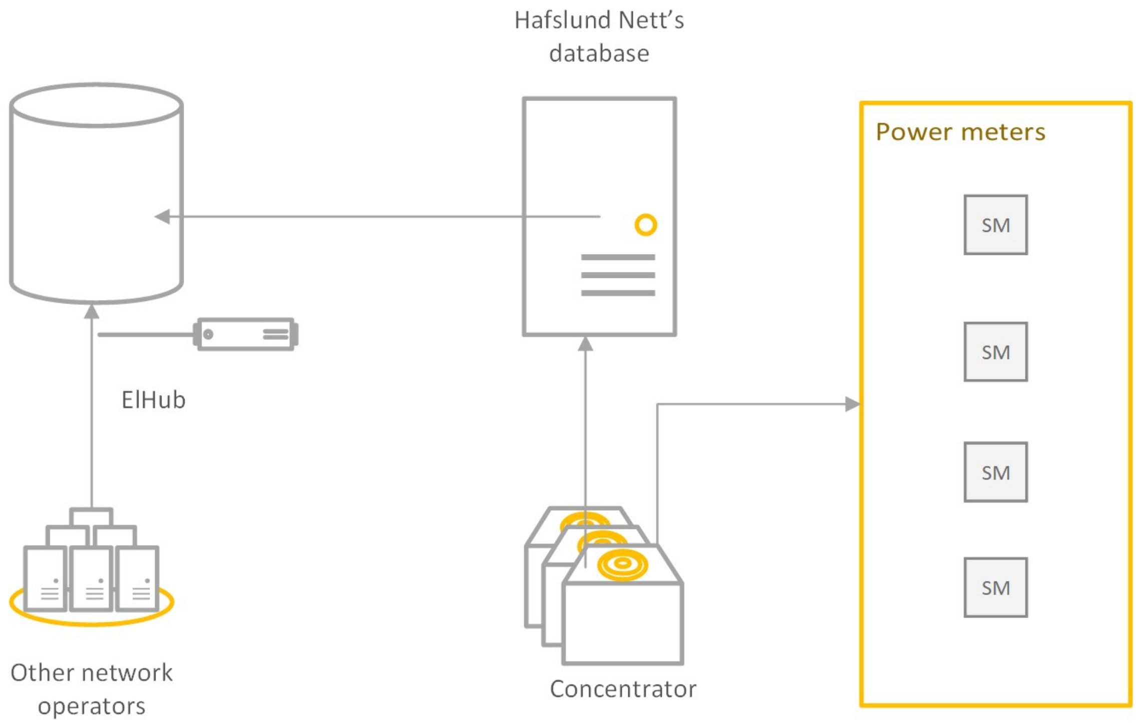

Figure 2: Hafslund Nett's AMS system

5.3.2 Hafslund Nett's grid as infrastructure

Most people would agree that electricity grids are infrastructure. However, for clarity, I will discuss its definition as infrastructure grounded in Star and Ruhleder (1996) as that is the definition of infrastructure I work with. Hafslund Nett's electricity grid is a prime example of the embeddedness of infrastructure, and how hard it can be to separate what is one infrastructure and what is another. Should the transmission, regional and local distribution networks be viewed as separate infrastructures, or are they the same? Are the electricity production sites part of the infrastructure, or separate? What about the homes, businesses and other users of electricity?

The average person does not need to think about how the infrastructure that supports their electricity needs work, rather, they only need to plug whatever needs power into a power outlet, and they get what they need. In this sense, it is transparent. And in that same vein, one does not need to think about the electricity delivery system unless one has to change a fuse, or if there is a power outage. The electricity infrastructure is only really visible upon breakdown. The introduction of electricity has made modern society depend on electricity, and modern society develops new needs for electricity and capabilities which make the electricity infrastructure evolve. It is in this sense linked with conventions of practice. As with public lighting infrastructure, the infrastructure spans everywhere people live, and has developed over several decades, being both stretched in reach and scope, as well as continuously building on an installed base of other knowledge and infrastructure, and how to behave in relation to electricity, how it can and cannot be used, how to pay for it etc. is learned as part of the community one grows up in. Lastly, the transmission of power between networks, the construction of the physical network, the power output in people's homes and the input from generators is all governed by standards.

5.3.3 AMS as a smart city project

The argument that AMS is a smart city project follows along the same lines as the one that DLC is, on the basis of Caragliu et al. (2011). AMS is a system that adds emulated intelligence (Nam & Pardo, 2011) to a part of the electricity grid that has not had it before. StatNett and other network operators like Hafslund Nett have had monitoring systems, sensors and actuators in the transmission grid and regional distribution grids previously, but have not had any sensors in the local distribution grids, relying on customer complaints to know when there is an error and to triangulate where it is located. AMS gives an advanced monitor in every electricity termination point in the local distribution grid, and new monitors in the transformer sheds. This gives valuable data and faster response times in case of error in the local distribution network. The main immediate benefit for customers is that they no longer need to manually read and report their energy consumption to their network operator each month, as the new smart meters will report consumption automatically. Secondly, the meters will report consumption hourly, so that billing will be more exact as customers can pay for the consumed electricity by the price it actually cost the hour it was used, rather than an average for the month.

The potential, however, lies in the future. The smart meter allows for automatic price and consumption information to be sent out from the meter through the HAN-port. This, coupled with home automation systems that several actors are developing, can allow for smarter power usage. Today, there are two peaks of power consumption in Norway each day, one in the morning, and one in the afternoon, which corresponds to when people are waking up, making coffee and showering, and to when people are getting home, starting to charge their electric vehicles and make dinner. Because of these peaks, the electricity grid needs to be designed to account for the biggest peak on the day with the highest power consumption (which is usually the coldest winter day of the year in Norway). This means that there is an enormous capacity in the network that is only fully utilised one day a year, and mostly not at all. By giving price signals through the smart meter to home automation systems, Hafslund Nett, NVE and other actors in the Norwegian electricity grid hopes to "move" these peaks, even out the usage during the day, and remove the need for massive capacity increases in the network. This will be cheaper for customers, and better for the environment.

On the basis of the infrastructure definition of Star and Ruhleder (1996) and the smart city definition of Caragliu et al. (2011), the Hafslund Nett case is a good fit for this thesis. It is an infrastructure investment, evidenced by the common sense argument that electric grids are infrastructure, along with the discussion of Hafslund Nett's system in relation to the eight dimensions of infrastructure. It is an infrastructure investment that will give better management of natural resources, as it allows for better use of existing network capacity, and overall less power consumption through smarter control of products that consume electricity. It will also help network operators with maintenance and monitoring of the local distribution network. By extension, this smarter control and monitoring can also improve quality of life for people through fewer errors and power outages, a basis for automatic home control systems, and also lower prices.

5.4 eSmart Systems

eSmart Systems is a relatively young company based in the Norwegian city of Halden. The company was formed in 2012 by a group of people that had previously worked within the electricity industry, developing and selling power exchanges. The reason for starting the company was, in the words of one of the employees at eSmart Systems, that

> *(…) crazy things are happening on the technology side of things, with Big Data, with the processor and storage capacity increases, and at the same time, one saw the regulatory change that was starting to happen on the power side of things with the introduction of AMS (…).*

They started developing data analysis, or big data systems for the power sector, but have gradually branched out into other sectors such as other utilities like water and gas, and other branches entirely, such as government and health care.

According to eSmart Systems, there is a massive generation of data in modern society, but these are all generated by separate systems or silos, and there is little to no communication between them. The silos are not necessarily only between sectors, but within companies as well. For example, electricity grid companies have several different professional systems used for a range of different tasks, such as customer information systems, geographical information systems, maintenance systems and automatic control systems. These have not traditionally had any communication between them. What eSmart Systems sees, is an opportunity to connect data from different sources within companies, and across sectors, to gain insights and possibilities for control, maintenance and decision making that has not been available before. In other words, eSmart Systems' perspective is that "we have specialised in taking those data, [into] a completely open kind of architecture, and can use our intelligence to find relationships, find bottlenecks, run predictions, predictive maintenance, more optimised use of what is already there".

5.4.1 System description

What eSmart Systems describes their system as, is a generic, cloud-based platform, that can be placed as a top layer over different existing systems, to extract data from them. Then it can correlate, analyse and gain insight based on those data, that can be used for planning, decision-making or automatic control. The system is based on different machine learning, insight and IoT services in Microsoft's Azure cloud service, and eSmart Systems cooperates closely with Microsoft, working on the leading edge of which services the cloud infrastructure platform can provide. On top of the Azure services, eSmart Systems has built what is currently eight main, generic components in their platform;

- **eSmart IoT**
  Used for managing and communicating with devices over the internet (similar to DLC's M2M server).
- **eSmart Asset Management**
  Which contains services for monitoring, analysis and maintenance of assets, such as transformer sheds and smart meters.
- **eSmart GridOps**
  Or Grid Operations, services for controlling and surveying a power grid or other utility grids.
- **eSmart Grid Plan**
  Used for planning and maintenance of utility grids.
- **eSmart Response**
  A collaboration platform for central control, such as the operations centre of a power distribution company, or a health care emergency room.
- **eSmart DERMS**
  Or Distributed Energy Resource Management System. Used for analysis and planning of flexible loads or resources in a system, and prediction of when they should be connected or disconnected.

- **eSmart Flex**

  System for controlling DERs (flexible loads/resources)
- **eSmart Trade**

  System for electricity trading, with focus on prosumers as well as production companies and distributors

These components are designed for specific purposes, but in as general a way as possible, to afford ease of reuse in different sectors. Examples are the eSmart Response component, which was initially designed for emergency rooms, and is currently being adapted for electricity control centres. The strategy eSmart Systems employs is that when they want to branch out to a new sector or domain, they should not have to do much more than to add a thin layer of business logic for the new domain.

This has allowed them to create their existing product line-up, consisting of Connected Grid, Connected Drone, Connected Prosumer, Connected Trading, Connected Health and Connected City. All of these products use a combination of the underlying platform properties, by combining the platform components in different ways. At the basis of all components of the platform, is a data lake, where all data that is generated from the systems connected to eSmart Systems' platform is timestamped and stored. A data lake is a kind of digital data storage where all kinds of data can be stored, both structured, semi-structured and unstructured. On top of this lies different analytics and optimising algorithms that are specific to the separate components.

As an example, a utility company in Florida, USA is using eSmart Systems' platform to determine whether or not their water consumption meters were reporting error numbers or not. Previously, they had to drive out to check the meter every time they received zero values from them because that could indicate that there was a problem with the meter. Looking at historical data of these check-ups, the utility company realised that a lot of those trips were in reality not needed and that if they could analyse the data they got from the meters in a smarter way, they could reduce the amount of unnecessary and expensive trips. Using eSmart Systems' system, they combine water and energy consumption data and were able to reduce the number of trips by approximately 80%, and according to their own calculations, save about 7 billion per year.

Another example is an energy grid customer of eSmart Systems that had recently replaced 10 transformer sheds because they, through their existing data and processes, assumed that the sheds needed to be replaced. After starting to use the eSmart Systems platform, and connecting data from different systems and analysing them, they realised only 3 of those 10 sheds actually needed to be replaced at the time they did, and the 7 other ones would have been working fine for a long while more.

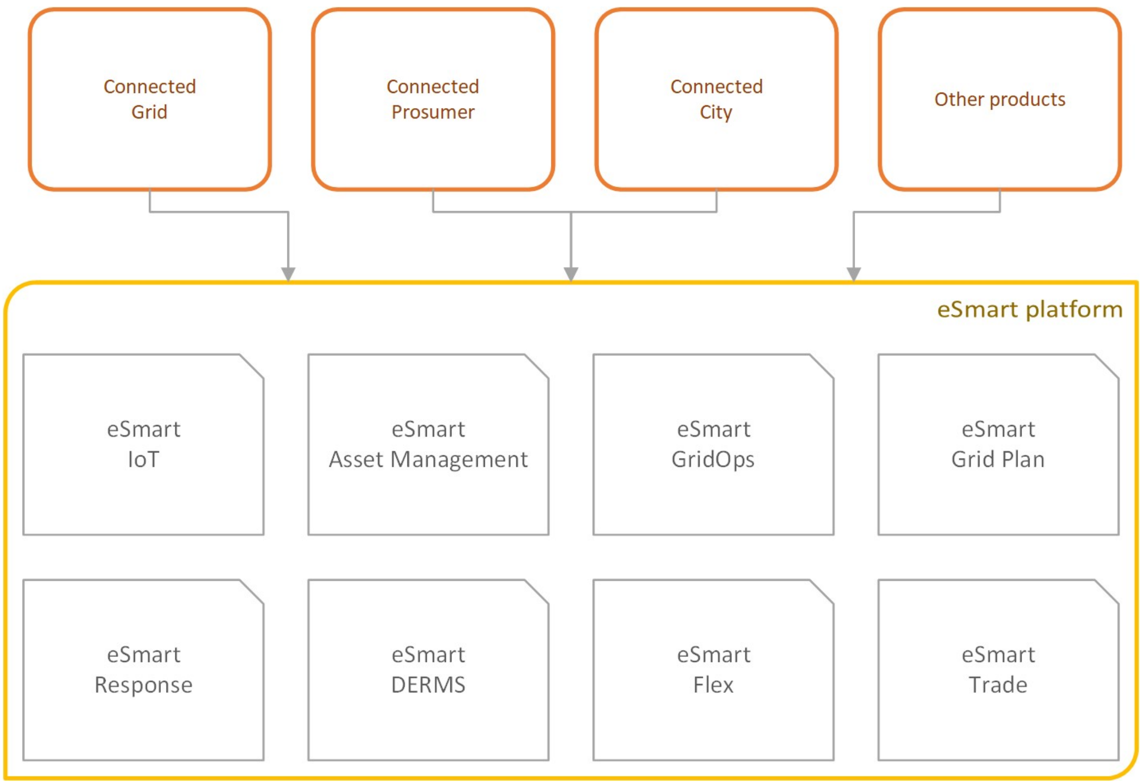

Figure 3: eSmart System's platform

5.4.2 eSmart Systems' platform as a smart city project

eSmart Systems is the case that is most obviously a smart city product. To begin with, the mission statement of eSmart Systems is "At eSmart, our mission is to build digital intelligence to provide exceptional solutions to our customers and accelerate the transition to sustainable societies". As the definition from Caragliu et al. (2011) states, investments in traditional and modern infrastructure that fuels, among other things, sustainable economic growth, and increased quality of life is part of building a smart city. Looking at examples of how the eSmart Systems platform is applied gives further confidence to being able to label this as a smart city product.

The system is mainly focused on being a part of investments in traditional and modern infrastructure, but also to some degree investment in human capital through their health case projects. One of the major goals of several of their products is better management of resources, both physical assets such as transformer sheds and electric power transmission towers, but also natural resources such as electricity and water, and also money. Some of the products also clearly work to improve quality of life, once again using the example of their health care solutions, that both allow health care workers to be more efficient through allowing sharing of data between different parts of the health care service, and by extension making health care personnel give better service to patients.

The platform eSmart Systems is building is not interesting as a case of infrastructure to this thesis. While it can be argued that the platform is an information infrastructure, it is not infrastructure in the same way as the ones operated by Hafslund Nett and DLC, because it is much smaller in reach and scope, and is not public infrastructure. It is rather designed to be placed as a component into other existing infrastructure, to give new capabilities and allow for new relationships in the existing installed base. There are three reasons why this case is interesting to my thesis, even though it does not satisfy the infrastructure criterion.

Firstly, it is a prime example of a smart city project, as was established in the previous section. Secondly, eSmart Systems is an example of a company that in many ways see the potential in opening up existing infrastructure in cities to allow for new connections between data and properties to create new affordances. They have worked a great deal with new possibilities generated by the introduction of AMS in Norway and is a such an illustration of the kind opportunities that arise by adding sensors and actuators to infrastructure, and interfaces where external systems can connect. Thirdly, eSmart Systems is a good example of how platform architecture and thinking allows for rapid innovation and adaptation to new contexts. They have built a stable, complex, rather generic core where most of the capabilities they want and need are built in, with clear, easy-to-use interfaces on which to build services that can utilise the core affordances. This makes it so that they can rather quickly move from what was developed as an asset management system for the power industry, and develop patient monitoring system using the same technology in a much shorter time than they would have used were they to enter health care with a completely separate product created from scratch.

In conclusion, eSmart Systems products are smart city products as per Caragliu et al.'s (2011) definition. They work with investments in human capital, and both traditional and modern infrastructure, and the products they build fuel sustainable economic growth, wise management of (natural) resources, and improves quality of life. To put it in the words of one employee, "this is win-win. It is cost-effective, we can earn a buck, and we can make the world a little better". While it is not infrastructure in and of itself, the system is built to be part of infrastructure, and exemplifies a lot of the possibilities of developing infrastructure in a more extensible way, as well as exemplifying the positive affordances that developing a system as a platform creates.

In the following chapters, I will answer the research question, *how can knowledge from research on platforms be applied to the development of smart cities?* I will begin with describing the theoretical basis for discussing the question and continue with answering the question through theory, and analysis of the case studies. At first, I will be describing the current state of city and infrastructure development, based on theory and the studied cases, argue for why platform development can positively affect future development, and then discuss how this development can be achieved.

Chapter 6 Oslo's smart city challenges

To begin to answer the research question, I will start by recapping the challenges facing smart cities identified in the literature review in chapter 2, that I believe can be alleviated to some degree using platform and information infrastructure theory. I will also summarise challenges reported by representatives from eSmart Systems, Hafslund Nett and Datek Light Control. In addition, I am going to see how these challenges and criticisms fit with Oslo's smart city development.

In the existing research described in the literature review of smart city literature in chapter 2, several challenges with how smart cities are developed and governed today are brought up. There are three challenges that I believe developing infrastructure with a platform architecture can improve:

- Smart city planners lack a holistic plan for the city (Cocchia, 2014).
- Cities tend to focus on either infrastructure or values and services (Neirotti et al., 2014).
- Development of smart cities tends to be driven by separate, unrelated projects, rather than being governed by the city planners (Cocchia, 2014; Neirotti et al., 2014).

As discussed in the case description of Oslo in the previous chapter, I have found that all of these can be seen in Oslo to varying degrees. I am now going to discuss these challenges in the context of Oslo and the other studied cases.

6.1 Lack of a holistic plan

As discussed in the case description of Oslo, the lack of a holistic plan has been identified and reported by the municipality itself, as it is described in the plan strategy for Oslo how the departmentalized structure of the municipality administration is not well fit for the cross-department cooperation that is needed to face the challenges of the future. This was also brought up by DLC in my second interview with them when talking about how they are currently getting contracts with the municipality. This is done through a public bidding process, where companies bid on delivering a complete lighting solution to the municipality. Currently, DLC is usually brought in as a partner by companies that build the actual light infrastructure, when they bid on a lighting contract for the city. However, as the representative from DLC states when explaining how they get contracts:

> *(…) if you think of a smart city solution, it's no longer just lights. Then it is water and sewage and renovation and all that other stuff. And then it isn't a lighting supplier that should answer that [bid]. And then the question is, who should answer such a bidding? (…) this has to be driven by a much higher level in the municipality, who say that* 'we need to be innovative here, (…) full-width infrastructure upgrade'.

In other words, the experience from DLC's point of view is that the current process of asking for smart functionality on a per-infrastructure basis is no longer adequate because much of the same basic functionality is needed for all smart infrastructure. Further, the representative spoke about how their experience is that smart city initiatives from the municipality are being started by the individual departments of the municipality, with little to no cooperation between departments that could use the same infrastructure for their solutions.

An example of this is a recent project from 2016 where Oslo municipality are testing out parking sensors, to create a service where drivers can be guided to the nearest parking spot (Klingenberg, 2016). This service is built up of sensors placed in the ground, that communicate over radio frequencies to a concentrator, that relays the information back to a central server. This is very similar to the network infrastructure DLC uses for their light control solution. The service could maybe have been deployed quicker, and could potentially have been cheaper if the parking sensors were connected to the existing wireless network that already covers most roads in Oslo, using DLC's communication infrastructure as a platform core, and building the parking functionality on top as complementary components.

I do not have any information on whether using existing solutions were discussed in this process, and there may be valid reasons that the municipality chose to build a new data network for the parking service. However, this serves as an example of where existing infrastructure built for a different purpose could very well have been used instead of building a new one, which would be easier for the municipality to do if there existed an overarching plan for developing, for instance, communication networks for their smart city solution.

Another thing that was mentioned by the representatives at DLC was that they did not know whom to contact with regards to smart city projects and development in Oslo. This was in line with my own experience when trying to get an interview about the city's smart city efforts. It seems that the observations by the municipality and the experiences of parties trying to contact Oslo about smart cities can confirm that Oslo faces the same challenge many cities that aspire to be smart face, a lack of a high-level function in the municipality that can govern and take control in the development of the smart city.

6.2 Focus on either soft or hard smart city development

One of the issues described in the literature review was that there are two streams of smart city development, where one is called the hard stream, and the other the soft stream (Neirotti et al., 2014). The hard stream of smart city development pertains to investments and development in infrastructures such as electricity and transport. The soft stream is focused on values, education and quality of life.

When looking at the smart city development in Oslo, it seems the city is currently focusing on both areas, but leaning towards the soft stream based on the available public information regarding Oslo's smart city strategy and goals. The goals from the municipal master plan mostly focus on outcomes for the citizens of Oslo, as does the description on the city's smart city web page. These outcomes mostly pertain to education, attracting businesses and educated citizens, and public services like health care. The fact that the municipality focuses on the outcomes for its citizens and the development of the city makes sense given the mandate that they have. The tasks of municipalities and city administrations in

Norway are mainly to do those things; develop the city in a way that benefits citizens and businesses.

This suggests that Oslo either by choice or chance have answered the critique from Hollands (2008) when he calls for cities to "start with the human side of the equation". It makes sense that the plan for the municipality and the specific projects such as smart parking has goals related to positive outcomes for the society or the citizens, as the focus of using technology and developing infrastructure should not be the development or technology in itself, it should serve as a means to an end. To once again bring up the Oslo smart parking project as an example, it entails building communication infrastructure that will register and report the availability of parking spaces, which is infrastructure and technology investment. But the goal of this project is to make it easier for citizens and visitors to find parking, which in turn, according to some research, has the possibility of reducing the amount of driving within central Oslo with up to 30%, with all the benefits this has for greenhouse gas emissions and air quality (Klingenberg, 2016).

It is an important point that most of the infrastructure development in Norway is governed by the state, rather than municipalities and counties. For instance, the power grid, railways and certain roads are to a large degree governed by the state (through directorates, agencies and state-controlled companies, as well as legislation). Thus, the hard stream that focuses on how technology can help with production and delivery of resources within a city is mostly the focus of the parliament and other state government bodies, as is the case with AMS.

This is not to say that municipalities in general and Oslo in particular do not care about or focus on infrastructure. Municipalities and counties are charged with developing local road networks as one example, and also public transport and schools to name a few other examples. Local administrations also care about the development of nationally governed infrastructure in their area. However, the conditions for how infrastructure that is governed by municipalities and counties should be developed and maintained, as well as the development of national infrastructure is decided by the parliament and government. Even though the possibility for municipalities to lay conditions for infrastructure development is limited, as I will discuss in the further sections, it could be a good idea for the city to increase its focus on infrastructure development, to fuel innovation and development of the soft smart city.

6.3 Lack of coordination between smart city projects

The last problem identified in the review of smart city literature that I will discuss here is that smart cities are developed as bottom-up collections of separate projects that together form a smart city (Cocchia, 2014). This seems to be somewhat the case in Oslo. Partly, this is related to the problem with how the municipality is organised and governs the development; the separate agencies start their separate projects that do not necessarily cooperate with each other, and there seems to be a lack of central control.

As examples that this is the case, the AMS development is not initiated by the city of Oslo; it has rather been decided by NVE as a nation-wide infrastructure investment, which in turn was decided by the parliament of Norway. Further, several separate agencies in Oslo are customers of DLC, and the smart parking project is initiated by the city environment agency. In addition, there are separate projects that are not directly connected to Oslo, such as Smarte Byer Norge[5] that work towards being a marketplace for data sets from both public and private companies, and Paadriv[6], a project working on developing a part of Oslo as a smart city.

6.4 Summary

To summarise, all of the three challenges described above can be found in Oslo, and some can be seen in the studied cases of DLC and Hafslund Nett's AMS solution. The lack of a holistic plan in Oslo, and the tendency that the development of Oslo is achieved through separate, uncoordinated projects, can

[5] http://www.smartebyernorge.no/omoss/
[6] https://paadriv.no/omoss/

be related to the fact that the departmentalized structure of Oslo's municipal government is not well suited for the cross-sectorial planning and development needs of developing a smart city. The issue of a tendency to focus on the soft stream of smart city development can be explained by the mandate that Norwegian municipalities have because infrastructure development is a government-level responsibility in Norway. Another result of the aforementioned points is that it is unclear who has the overall responsibility for developing Oslo as a smart city, which was reported as an issue by DLC, and where I faced difficulties in getting an interview with representatives from Oslo.

In the next chapters, I will discuss how platform thinking and platform architecture can help alleviate the issues described in the sections above. I am going to argue that developing platform infrastructure can be an important place for municipalities to place their smart city development focus, that can be a part of the solution when working towards a holistic plan, a unified focus on all sides of development, and coordination between different actors.

Chapter 7 The role of infrastructure in city development

In this chapter, I will argue that how the infrastructure in a city is developed, is an important determiner for what kind of city is developed. In other words, whatever culture or function a city wants to support, it needs infrastructure that can support these things, or it will be hard or even impossible to achieve. I will then go on to argue that infrastructure development is a natural focus for city administrators and country governments to have because they already in many cases possess a great deal of control over the public infrastructure in their regions.

7.1 Significance of infrastructure in cities

Cities are built on infrastructure, and most processes, activities and services in the city are supported by one or more infrastructures, in several forms. An example is the possibility for citizens to move about, which is supported by and relies on infrastructures such as subways, trams, buses and railroads, as well as the public road network for pedestrians, bicyclists and cars. Another example is electricity, that not only support the needs of the citizens in their daily lives but are critical for other infrastructure such as trams and subways to work, as well as for important institutions like hospitals.

A city cannot function without, and is both shaped by and shapes the infrastructure it builds on, as per the definition of infrastructure given by Star and Ruhleder (1996). Because a city will be shaped by the infrastructure it builds on; it is important to build an infrastructure that can support the city that the government and citizens want to live in. A city that is heated mostly by oil furnaces and fireplaces, will have a hard time reducing air pollution because these heating sources release a lot of particulate matter, and a city with an inefficient public transport system cannot support a culture of choosing public transport rather than private cars because it would be hard for citizens to manage their daily lives with a public transport system they cannot rely on. This means that if one wants a city that is environmentally friendly, efficient, is pleasant to live in, and that enjoys a large degree of innovation, one needs to develop infrastructure that can support those things.

7.2 Government influence over public infrastructure

In Norway, as in all countries of the world, the state holds at least some, and in many cases a lot of control over the infrastructure that is defined as public infrastructure. In some cases, the state fully owns and operates the infrastructure through a state-owned company, as is the case with the central power grid in Norway. Other infrastructures are partly state-owned, as is the case with the regional and local power grid in Oslo, where Oslo municipality is a majority shareholder in the company that owns Hafslund Nett, Hafslund ASA.

In any case, whether an infrastructure is operated by private or state-owned companies, there is a high degree of regulation with regards to how the infrastructure should be developed, and what it should be capable of. In the cases where the government does not build infrastructure or services itself, a bidding process is set up, where the government body responsible for ordering the service or infrastructure define what should be a part of it, and which features it should have, and private companies are then welcome to bid for delivering that solution on the terms of the government. In all these cases, the government has a high degree of control over how these services and infrastructure should be developed. This means that the power to develop infrastructure in a city to support an innovative smart city is to a large degree in the joint hands of the state and municipal administrations.

In the above paragraphs I have described how a city is shaped by and can be constricted by the way its infrastructure is built, and the capabilities it can provide, and thus need to focus on developing an infrastructure that can support the city one wants. In addition, I have argued that the administration of most cities – and definitely in Norway – have the ability to decide which direction public infrastructure should be developed in through ownership and bidding processes. I will now go on to discuss which features infrastructure backing an innovative city should have.

7.3 Traits of smart city infrastructure

A smart city needs to find new solutions to complex problems, and utilise technology in new ways to solve the challenges that face modern cities. Because the smart city is dependent on finding new solutions and novel ways of using technology, innovation is something that needs to be fuelled and developed within the city. Part of the equation of innovation is attracting the people and businesses that can innovate, and this is a stated goal for Oslo, as well as many other cities that strive to be smart (Hollands, 2008). However, the cities cannot be innovative solely on the basis of innovative people; they also need an infrastructure that can fuel and support innovation.

The infrastructure needs to have the ability to be easily adapted, utilised and extended to mitigate new problems and serve new purposes. These are traits of a generative information infrastructure (Zittrain, 2006). As described in the section on information infrastructures in chapter 3, Zittrain (2006) defines generativity as a function of a technology's capacity for leverage across a range of tasks, adaptability to a range of different tasks, ease of mastery, and accessibility. Generative mechanisms are used as an explanation in information infrastructure theory for how components in an information infrastructure combine in unexpected and unintended ways, prompting changes in the infrastructure, and the ways in which it is used (Bygstad, Munkvold, & Volkoff, 2016). This is a trait that is desirable in an environment where innovation is important because it builds up under the combination of existing components in a system to create new functionality and solutions.

Infrastructures where the installed base has little capacity for leverage across a range of functions, and that is not adaptable to new situations and functions will hamper innovation, rather than drive it. An electricity grid without the capabilities that are added by AMS cannot support a society where a large part of the population are energy producers as well as consumers because the power grid would not be able to handle the fluctuations in voltage that could be caused by a fleet of solar panels on a sunny day. The infrastructure in a city would benefit by being developed in such a way that it is generative because of the elements laid out in the above arguments. A generative information infrastructure needs to be backed by a generative architecture, according to Zittrain (2006)

By developing the infrastructure of a city in a way that emphasises the generative traits of the infrastructure, one will be facilitating how components in the infrastructure can interact with each other in new ways, that allows for it to be used in ways that were not envisioned when it was first created, and in ways that releases potential in the infrastructure that one did not know existed in it, because unforeseen and uncoordinated change is the result of generativity (Henningson & Hanseth, 2011).

When viewing the city as a complex socio-technical network, new combinations of the components in the city (for instance infrastructures) can be utilised to create new services and functions. This can have a positive impact on how easy it would be for the municipality to develop new services for its citizens and other entities in the municipality. It could also make it easier for companies answering bidding rounds to come up with clever solutions to problems the city faces, in a cheaper way than before by reusing core components of the infrastructure that are already there. Lastly, it could make it easier for companies and individuals in general, to create innovative new solutions and services that the municipality or other entities had not even thought of as possible, by combining components of the city in a new way.

To summarise the preceding sections; it is important that a city that wants to become smart, does so in part by developing their infrastructure in a way that supports this. There are several outcomes that are desirable in a smart city, and according to Caragliu et al. (2011), sustainable economic growth, high quality of life, wise management of resources and participatory governance are high-level goals. None of these can be directly achieved by infrastructure development, but, as is pointed out in the definition, infrastructure investment fuels them. For infrastructure to support development and change in the services and processes it supports, it needs to itself be able to develop and change.

One way in which this is achieved is through the phenomenon of generativity, where components of the infrastructure combine in unexpected ways to form new ways of usage and new services. This generativity can be utilised to create new services and solutions that can lead to the outcomes that one wants in a smart city. For an infrastructure to be generative, it needs to be backed by a generative architecture. In the following chapter, I will make the argument that platform architecture is a generative architecture and that developing infrastructure as platforms can lead to the positive outcomes described in this section.

7.4 Summary

In this chapter, I have argued that how the infrastructure in a city is developed greatly influences in which direction the city itself will and can develop. Because infrastructure supports most of what goes on in a city, the capabilities of the infrastructure will both shape the city and constrict how it can be developed. Infrastructure, according to Star and Ruhleder (1996), both shapes and is shaped by the context it exists in. This means that while the infrastructure of a city shapes the development of the city and can decide which direction the city can develop, the city – meaning among other things the citizens and government – also shape how the infrastructure develops, and this can be an important way in determining which way the city should develop. This is made possible by the fact that regional and national authorities in Norway and in most of the world, maintain a great deal of control over how public infrastructure is developed.

Following the argument that cities should focus on infrastructure development and that they have the means to do so, I have argued that this development should be focused on developing the infrastructure in a way that enhances its generative traits.

Chapter 8 Developing smart city infrastructure as platforms

In this chapter, I will begin by arguing for the possibility of developing infrastructure into platforms, before going through some of the differences between platforms and other kinds of information infrastructures. I am then going to discuss whether platform architecture is a good architecture to apply to city infrastructure, by looking at whether platform architecture is generative architecture.

8.1 Developing platform infrastructure

As discussed in the introduction to platforms, platforms and information infrastructure are related concepts. Based on Plantin et al.'s (2016) understanding, I see platforms as a specific instance of information infrastructure, that differs from other kinds of information infrastructure in some key areas. Because platforms are information infrastructures, it can be possible to develop existing information infrastructures that are not platforms, into platforms.

8.1.1 Similarities between platforms and other infrastructure

As established when introducing platforms, a platform consists of a highly stable, complex core, with well-defined interfaces that allow outside – or complementary – components to leverage the capabilities that exist in the core components. Hanseth & Lyytinen's (2010) definition of information infrastructures that was introduced in the theory chapter, is that an information infrastructure is "a shared, open, heterogeneous and evolving socio-technical system, consisting of a set of IT capabilities and their user, operations and design communities." This holds true for both platforms and information infrastructures. I will argue that the eight dimensions of infrastructure posed by Star and Ruhleder (1996) are also common between platforms and general information infrastructures. Given that they share the same basis; it is reasonable to assume that information infrastructures can be developed to become platforms.

8.1.2 Differences between platforms and other infrastructure

There are several things that set platforms apart from other kinds of information infrastructures. A key difference is the fact that in general, platforms are owned, operated and controlled by one or a few entities, while in general information infrastructures are controlled by a large, uncoordinated group of entities (Plantin et al., 2016). Another important distinction is the fact that platforms are built to maximise the possibility of being developed on and extended by third parties. Where the focus on development, or cultivation, of information infrastructures lie in standardisation processes and the tension between stability and change, and standards and flexibility between components in the infrastructure, the focus in development of platforms is on creating well-defined interfaces to allow outside, or complementary, components access to the properties of the core components (Plantin et al., 2016).

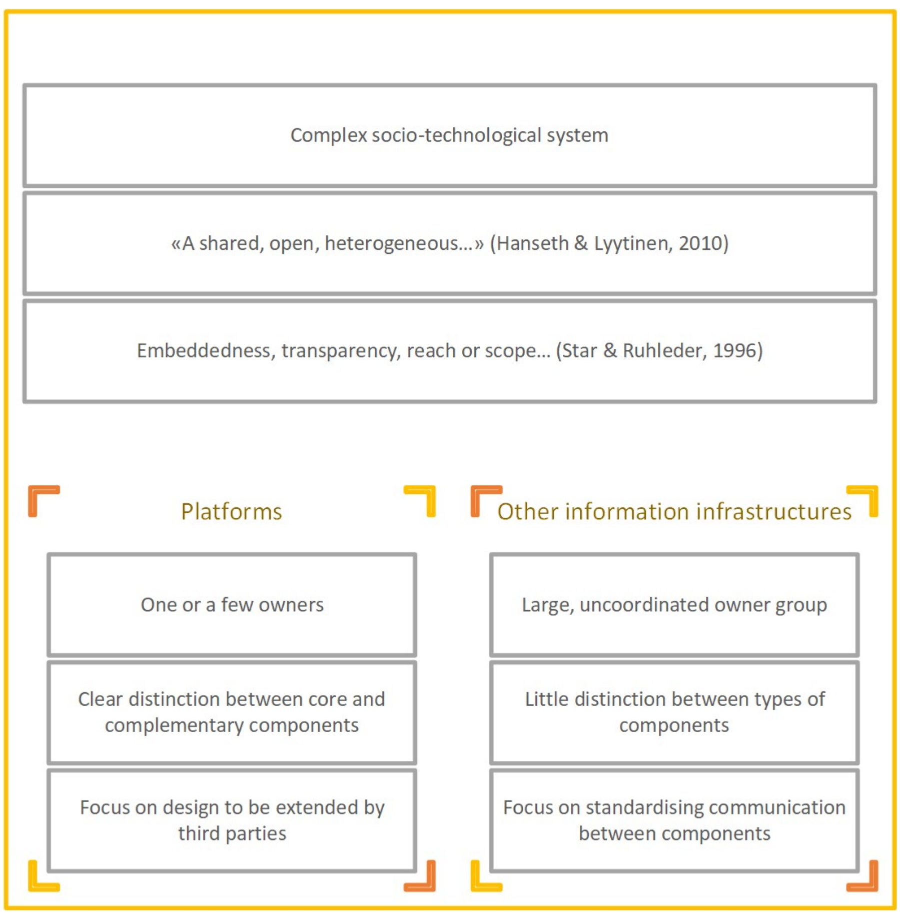

Figure 4: Differences and similarities between platforms and other kinds of information infrastructure

The difference between information infrastructures and platforms is in some way a difference in perspective as well. The core of a platform can be seen as an information infrastructure in itself. It is shared by the components that build on it, and the organisation that owns and operates it, open to third parties for development and heterogeneous and complex because of the multitude of systems and physical infrastructure, as well as laws and regulations it has to adhere to, and the organisation it is built and operated by. In a platform, the owner defines what is part of the core of the platform, and creates interfaces into this information infrastructure. The complementary components are then viewed as extrinsic to the core, as components that build on it but are not part of it (Tiwana, 2013). In the traditional, non-platform, way to view information infrastructures, the interfaces and complementary components would be viewed as a part of the same information infrastructure as the core components, and there would be no distinction in which components served which purpose. In this information infrastructure view, everything that is currently part of the infrastructure is the installed base (Hanseth & Lyytinen, 2010), and there is no distinction between which components are part of a core, and which are not.

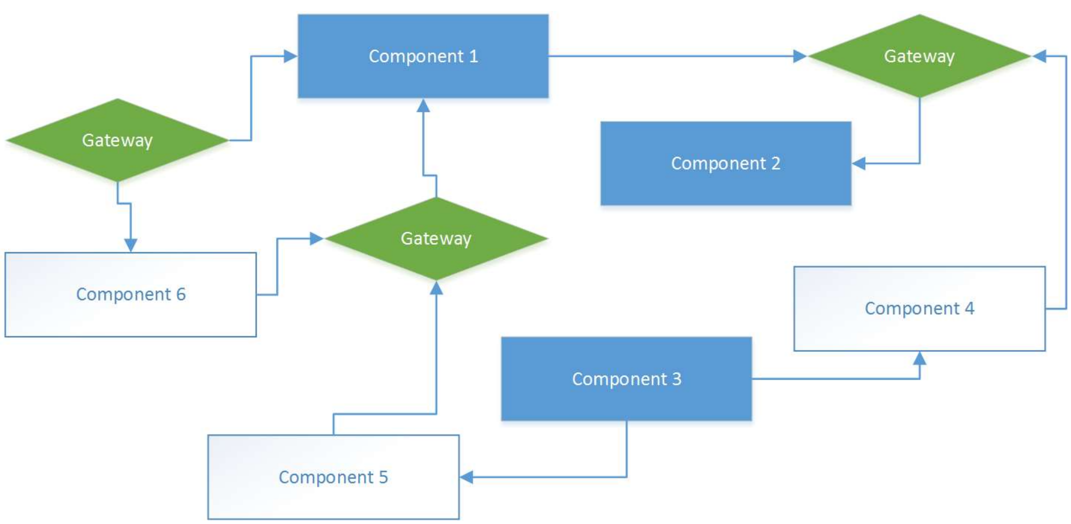

Figure 5: Information infrastructure view of a system.

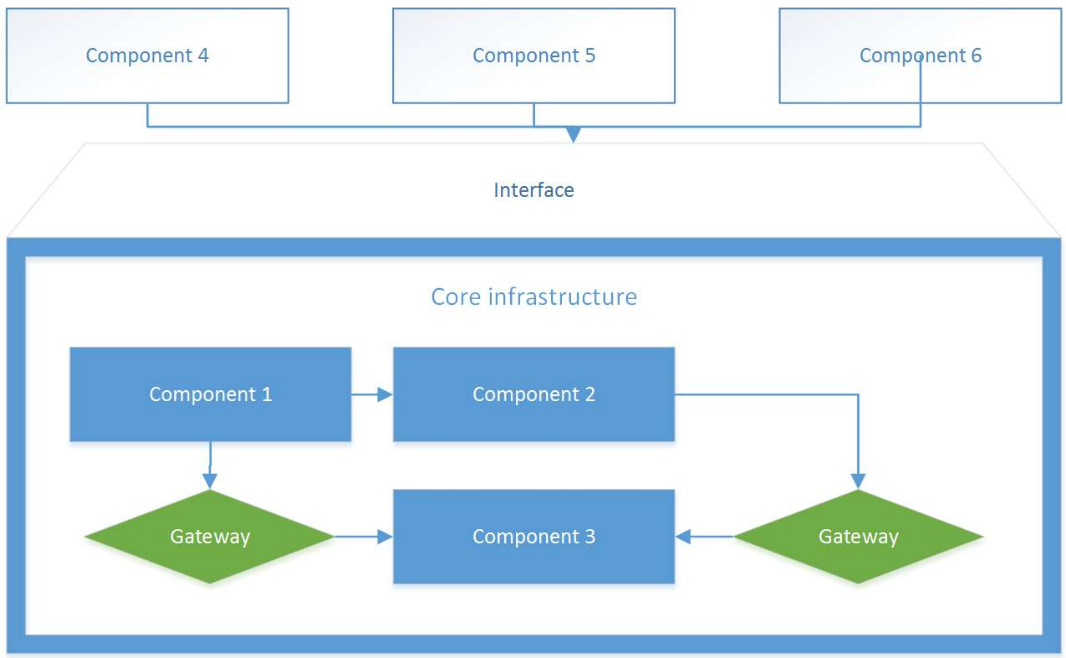

Figure 6: Platform view of a system.

8.2 Generative properties of platforms

In the previous chapter, it was described how an innovative city would benefit by being backed by generative infrastructures, and that generative infrastructures would need to be backed by a generative architecture, which would incorporate generative mechanisms that would maximise their capacity for leverage across applications, adaptability to a range of situations, and be accessible and easy to master (Zittrain, 2006). I argue that platforms embody all of these things.

Their capacity for leverage is evident in the way the capacities of the core of the platform is built to be leveraged through the defined interfaces. The platform is specifically designed to allow other parties outside of the organisation controlling it to leverage the functionality that is built into it. Adaptability of the core to different use cases is, in market-driven platform development, imperative for the platform to survive. The platform should be able to do what its users and developers want it to do. It is also important for a platform in a market situation to be both easy to master, for users and developers alike, as well as accessible for the same groups. If developers and users cannot learn to use the platform, or access it in an easy manner, they will probably not bother to develop and/or use the platform (Tiwana, 2013).

I have so far argued that infrastructure can be developed to become platforms because they share the same basis. Both are infrastructure, but platforms are infrastructures with a specific architecture that other infrastructure can be developed to have. I have also argued that platforms are generative, and, building on the argument from the previous chapter that generativity is very beneficial for a city to be innovative, argued that platform architecture is a good way to design and develop generative infrastructure. I will now discuss how the generative and innovative capabilities inherent in platforms work.

8.3 Innovation in platforms

There are two main ways in which platforms concretely work towards increasing innovation. The first one is that platforms form an installed base of existing capabilities and services that can be utilised when developing a new component, and that will greatly speed up this development because of the already existing functionality (Plantin et al., 2016). The second is called mash-ups (Plantin et al., 2016), and consists of taking data or capabilities from two or more separate platforms, and use them together to create new functionality that none of them could do on their own. I will describe both of these below.

8.3.1 Innovation from installed base

When creating a new service, building or institution in a city, it needs to be backed by some form of infrastructure. If a city wants to create a new bus route, there has to exist a road for the bus to drive on, and that road needs to exhibit the properties needed for the bus to be able to drive on it. It needs to be wide enough, and have places along it where the bus can stop to pick up and let off passengers, as well as space for the bus to turn around to be able to drive back when it reaches the end of its route. The same goes for a new subway line, it needs tracks to drive on, platforms to stop by, and electricity to run on. A new building needs water, sewage and electricity infrastructure to support it, as well as transport infrastructure to allow people and transports to access the building both during construction and use. Because the infrastructure is there, readily available, it is easier to build a new house in a city than in the wilderness. Because buses are more adaptable to different kinds of roads, and because the road infrastructure is more ubiquitous in cities than rail infrastructure, it is easier to create a new bus route than a new subway route.

In these examples, one can view the backing infrastructure as platforms, that the complementary components of buses, subway cars and buildings build on, to avoid creating the capabilities they build on themselves. Platforms allow creators of new services to build on the capabilities and services that are already built into the core of the platform and allows the creators of the new service to save both time and money when developing it (Plantin et al., 2016).

8.3.2 Innovation from mash-ups

The second way in which platforms enhance generative properties lies in mash-ups (Plantin et al., 2016). Mashups are when properties and data from two or more different platforms are mixed together to create a new service with properties and functionality that was not present in the platforms the mashup built on when they were separate. The new service is greater than the sum of its parts. This is an example of emergence, as understood in assemblage theory and introduced in the section on information infrastructure theory (Henningson & Hanseth, 2011). Two assemblages, meaning two infrastructures, display new capacities in their interaction with each other, that none of the assemblages were capable of on their own.

Of course, there are instances where data or functionality in infrastructure should not be easily shared or controlled from the outside, for instance, because of privacy or security issues. I will discuss these challenges in a later section. As I have established how platforms theoretically work to improve smart cities, I will go on to discuss how developing infrastructure as platforms would work, and which effects it could have on a smart city

8.4 Prerequisites for smart city platforms

In this section, I will go through how smart city infrastructure can be developed to become platforms. I will argue that there are two important aspects to it; the first is that the infrastructure needs to have capabilities that it is possible to build interfaces to connect with. The second aspect is that the infrastructure needs interfaces that can be reached by outside actors.

8.4.1 IT capabilities

As mentioned above, the first, basic aspect to allow development of infrastructure into platforms, is that the infrastructure has capabilities built into it, that it is possible to create interfaces to. As I view platforms as an instance of information infrastructure, platforms by definition need to contain "a set of IT capabilities" (Hanseth & Lyytinen, 2010). The infrastructure needs to have for instance sensors that can collect data needed for monitoring, analysis and control of the system and/or automated control systems that can be controlled through IT systems.

Without these, the capabilities of the platform cannot easily be reached through an interface. As an example, the introduction of AMS adds these IT capabilities to the local distribution grids of Norway, where there have previously been no automatic control systems, and no automatic sensors reporting to a central repository. As a first effect, the AMS system simplifies electricity consumption reporting for consumers. Where they previously had to locate their physical, mechanical power meter, read off the amount of kWh that was currently shown, and send this to their electricity provider, the meter can now report consumption itself, over wireless communication. Of course, this effect is not enough to warrant the cost of installing these meters and their backing infrastructure. However, the effect of getting these data available through IT interfaces can potentially be enormous. Through these data, the electricity network operators can now see where there is an error in the local distribution grid, and fix it quicker than before, when they had to rely on customers calling in to be able to triangulate where the error has occurred.

The availability of this data also opens up the possibility for home automation systems to take electricity prices into account when controlling appliances in a home. This, in turn, allows the electricity network operators to use electricity pricing to even out consumption peaks that would have warranted unnecessary capacity increases in the network otherwise. It also allows for electricity consumers to start producing their own electricity through solar panels and wind turbines, and sell this electricity back to the network operator. All of this functionality would have been hard, if not impossible to implement, if the sensors that register electricity consumption had not been changed from a mechanical, manually read sensor, to an electronic, automatically read sensor and because of this, IT capabilities in infrastructure is important for the development of smart cities.

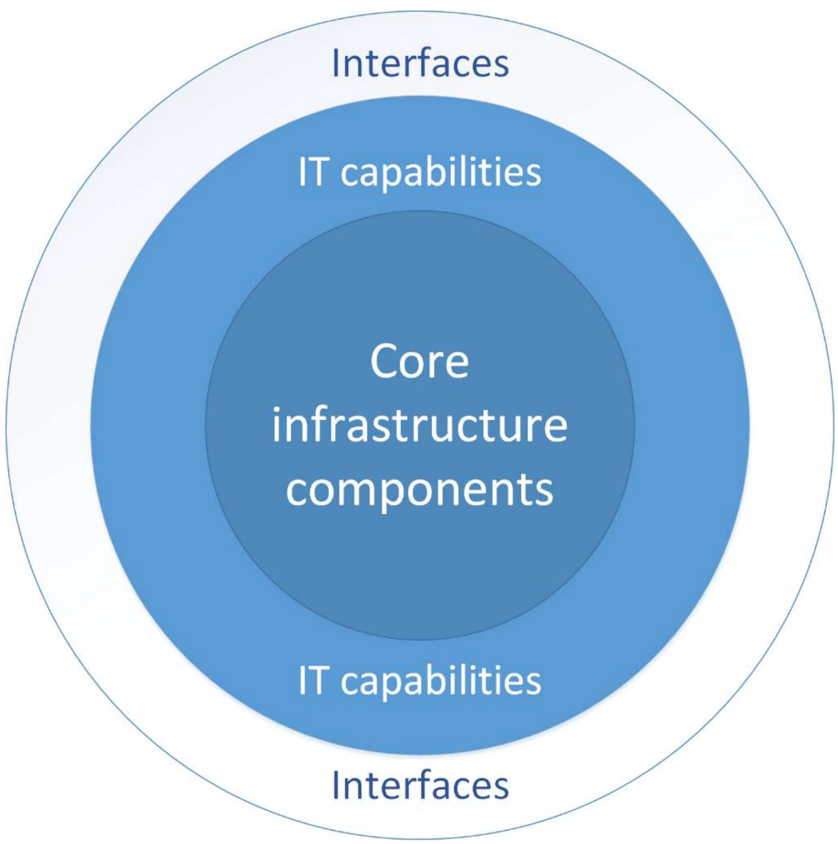

Figure 7: The conceptual structure of platform infrastructure

8.4.2 Interfaces

The second aspect that is needed is interfaces that allow outside actors and systems to connect to and leverage the capabilities of the infrastructure. Platforms by definition need to have interfaces that allow core components to communicate with complementary components (Tiwana, 2013). As discussed in the previous section, the two main innovation driving properties of platforms are that they allow for rapid and cheap reuse of existing capabilities, and that they allow for combination of capabilities from several platforms to create new services that the platforms could not deliver on their own (Plantin et al., 2016). The capabilities needed for these properties are the IT capabilities described above, but the innovative benefits of platforms will not be as great if there does not exist interfaces to leverage these capabilities.

As an example, the automatic reading and reporting of electricity consumption would not generate any other positive benefits than letting people not report their power consumption manually, if there did not exist interfaces that would allow home automation systems to connect to AMS to get this metering as well. Another point is that the mash-ups described in the previous section, where capabilities and data from several platforms are combined to create new functionality (Plantin et al., 2016), would not be possible if the platforms did not have interfaces that their data and capabilities could be reached through.

In summary, for information infrastructures to be developed with a platform architecture, there are two basic prerequisites that need to be fulfilled. The first is that the information infrastructure needs IT capabilities like sensors and actuators that can monitor and control infrastructure. The second is that it needs interfaces to allow external components to connect to and build on the capabilities inherent in the smart city infrastructure.

So far through chapters 6, 7 and 8, I have discussed the current state of smart cities and argued for the possibility of developing smart city infrastructure into platforms. First, I have identified and discussed several of the challenges facing modern smart cities according to current research. Then, I have argued for why infrastructure development can be an important part of building a smart city and meeting these challenges. Lastly, I have argued for why generativity is an important mechanism to drive innovation in smart cities, and how a platform architecture is a generative architecture that can benefit smart cities. In the following sections, I will discuss how platforms can be utilised to increase the generativity in a smart city, both on a theoretical level, and by discussing the studied cases.

8.5 Platforms as a driver of smart city generativity

In this section, I will present the argument that the generativity – or the level of development of innovative services and uses of the existing infrastructure in a city – would increase if one allowed other actors than the operators themselves to build on the capabilities of the infrastructure. This could open up for emergence in the infrastructure, which is the concept from assemblage theory that describes how components in a system have properties that are only visible when that component interacts with another component (Henningson & Hanseth, 2011). I will argue that the possible uses and functionality in existing infrastructure cannot be known beforehand, and much of it can only emerge when combined with other components that are owned or created by other actors than the infrastructure owner, and that it is therefore important that it is easy for these other actors to connect to the infrastructures of a smart city.

8.5.1 Smart capabilities in smart city infrastructure

Most infrastructure today have some form of IT capabilities used for monitoring and control. These systems have mostly been implemented because they make it easier for the owners or operators of the infrastructure to maintain and monitor the infrastructure. The national public road authority (NPRA) in Norway have systems that monitor traffic and congestion on the highways in Norway[7]. The local public transport company operating in the counties of Oslo and Akershus, Ruter, have systems that monitor where buses, trams and subways are, and

[7] http://www.reisetider.no/reisetid/forside.html

where their stops are. There are systems controlling and monitoring the water and sewage systems in Oslo, that report when something is wrong, and there are monitoring and control mechanisms in the central and regional distribution grids that serve the same purpose.

These systems were all built for monitoring and maintenance for the organisations that control the infrastructures. However, as an example of generativity, the NPRA's monitoring systems have been utilised to create a website where motorists can see the estimated travel times on the roads they need to drive on, based on the amount of traffic registered by the NPRA. Ruter's monitoring systems are utilised to give real-time information on the public transport stops about when the next departure will be, based on where the public transport vehicle is at the moment. These are all examples of how infrastructure owners build smart capabilities into their systems to be able to operate them better, and in some cases has seen a potential for added value for their customers.

8.5.2 Emergence and generativity in smart city infrastructure

DLC has a rather generalised M2M server, that can receive data from sensors, and send control messages that control actuators. Today, their system collects data from the light fixtures themselves about status, from power meters on how much electricity is used by the lights, from lux meters[8]. The system currently uses this data to report status on lights, and turn them on and off. These systems are built because owners of lighting infrastructure wanted an easy way to monitor and control them. However, there may be capacities in this part of the infrastructure that could emerge in combination with components in other systems or infrastructures, owned by other actors.

The lux meters are one example. They are now used to turn lights off and on based on the amount of light in an area so that lighting can be turned on at dusk and off at dawn automatically. But this data could be useful for other actors too. There could potentially be systems that would benefit from performing some

[8] Sensors that measure light strength

action in accordance with light changes. Instead of building a separate light measuring system these systems could use data generated by DLC's infrastructure. Maybe the data could be useful for meteorologists to get sunrise and sunset times for locations, or to determine how cloudy an area is by measuring how reduced the light is. Maybe it could be combined with other data or capacities to create new value.

Another example based on weather, where there are potentially unexercised capacities, can be seen in the fact that weather impacts the performance of wireless technology (Luomala & Hakala, 2015). Among the phenomena that are known to have an impact, are clouds that cause reflection of signals, water or humidity that blocks or impedes signals, and temperature that affects signal strength. There is a potential that signal strength data, combined with meteorological models can be utilised to turn wireless transmitters such as DLC's gateways and ZigBee nodes, or a mobile network operator's base stations into weather stations that can generate high-resolution data describing local precipitation, temperature and overcast.

These are all examples of emergence, as it is described in assemblage theory (Henningson & Hanseth, 2011). Emergence here is evident because the capabilities of the components of infrastructure can potentially be combined with other components to give new functionality and capabilities that would have been impossible otherwise. The probability of discovering these dormant capabilities of interaction increases if the restrictions on who are allowed to connect to an infrastructure are not extremely tight and if the infrastructure is built and structured to be connected to and utilised in this fashion easily.

An additional point that is not about unknown capacities, but where there is a potential for reusing existing infrastructure is the data network that DLC has built out. As mentioned earlier in the section on smart city challenges, this is a data communication network that spans all places where there is lighting that is controlled and follows roads and other public infrastructure that is lighted. Other systems that are dependent on a data carrier to transfer messages could utilise this same data network, like the previously mentioned parking sensors in Oslo, or control systems of other infrastructure like water and sewage.

8.5.3 Summary

There are two main points I am making with the above paragraphs. The first point is that the possibilities for using platform capabilities in new ways are impossible to know beforehand, as their capacities of interaction with others are hidden until exercised, but examples and research show that if you have adaptable and leverageable, accessible and easily mastered capabilities, new ways to use these capabilities will emerge. The second point is that which capabilities in an infrastructure that is useful, and for which purposes they are useful, depends on the situation in which they are used and with which other capabilities they are combined with. A capability may be added to the infrastructure for one situation, but someone might be able to use the same capability in another way, in another situation. This means that if a city wants to build infrastructure as platforms, then firstly the infrastructure needs to be created in a way where IT capabilities are added to the infrastructure, to allow it to be controlled and monitored, and secondly the infrastructure owners need to create interfaces through which the IT capabilities can be communicated with, to utilise the capabilities of the core infrastructure.

8.6 Potential benefits of developing platforms in smart cities

In this section, I will try to concretely describe which benefits a city and actors in the city would get from developing infrastructure as platforms. I will split this section into four; first, I will describe how this is positive for infrastructure owners and operators of the city, and second, I will continue with how it benefits businesses. Then I am going to describe how the effects can help citizens in the cities, before lastly summarising how this will benefit the city development as a whole.

8.6.1 Benefits for infrastructure owners

As a basic benefit and incentive for platform development, infrastructure owners would gain valuable monitoring and control systems in their infrastructure by introducing this kind of IT capability into the infrastructure they operate. As discussed earlier, most infrastructure already has this, at least to some degree, because of the obvious benefits automatic monitoring and control gives to the operators of the infrastructure. To once more draw on the example of AMS, the new monitoring this new technology enables allows Hafslund Nett and other network operators to more quickly discover and fix errors in the electricity grid and more efficient and correct reporting of consumption by consumers.

Another element that directly benefits the platform owners is the ability they gain to be able to add extra services to their infrastructure, that builds on the core functionality of the infrastructure. This can be customer focused services like the Norwegian National Public Road Association's (NPRA) map of traffic congestion and travel times, or internal systems that can help with the maintenance and operation of the infrastructure.

All of these added capabilities, together with the basic ability to extract data from the infrastructure and control it, is something that can make the infrastructure more relevant and more competitive. It can also enable the owner of the infrastructure to make money by offering access to the interfaces to their platform for a fee, or by making the infrastructure more attractive to pay for access to. This is especially relevant for infrastructure operators that have to compete with other companies over running public infrastructure. DLC's solution gives them an edge because they are able to add other capabilities to their solution quickly, and they are able to function as a data network for other systems (like they do with the pumps in Oslo's drinking water source), and they have the possibility of controlling other kinds of infrastructure. They can also provide more than just turning the lights in an area on and off based on dusk and dawn. Because of the system they have built, with role-based access and web API's that can be communicated with by for instance mobile applications, they are able to offer solutions like the ones where football team managers can control the lighting on the arena they play on, rather than the light being on for an entire evening as was described in chapter 5.

Another benefit for infrastructure owners, is the fact that because third parties are given the opportunity to innovate on the basis of their infrastructure, these third parties could potentially generate ideas that can be used by the infrastructure owner to make the infrastructure better, or use it in ways in which the infrastructure owner had not thought of on its own. This could happen both through the infrastructure owner acquiring or copying a solution and building it into their infrastructure, but also by allowing third parties to develop and deliver services that benefit the infrastructure owners, but that they do not have the time, money, capacity or will to do by themselves.

An example of this is a function called aggregator that representatives from Hafslund Nett have mentioned as an opportunity. An aggregator is a company that acts on behalf of several electricity customers in relation to the electricity network operator, to allow for load flexibility both from appliances that place a high load on the grid and from electricity production by consumers from for example solar panels. This will be described in further detail in section 8.7. The aggregator function would directly benefit Hafslund Nett, because they gain the ability to reduce load and increase production in parts of the electricity grid when they need to, based on the consumption and production of individual customers. However, they do not want to implement this service themselves, both because they do not see it as a part of their core business, but also because Norwegian authorities, as well as the EU, do not want grid companies to have individual deals with consumers of their infrastructure because they are monopolies. By having easy to use interfaces towards the parts of Hafslund Nett's infrastructure that will benefit from and work with an aggregator, it will be easier for Hafslund Nett to find a company that can provide this function on their behalf.

8.6.2 Benefits for businesses

For businesses and other entities that develop infrastructure and services in a city, the benefits of developing infrastructure as platforms would at the basic level be that they gain the possibility to easily build services and new infrastructure on top of existing functionality that they would otherwise spend a lot of time, money and resources on developing on their own. In some cases, it would also make it possible to create services that would have been impossible for anyone other than the owners of the infrastructure to build. It would also be possible to create services that build on several infrastructures, that the individual owners of the infrastructures would not want to build themselves, but that is made possible by combining them. Both of these are examples of the innovation capacity in platforms that was described in section 8.3, where the former is an example of innovation from installed base and the latter on innovation from mash-ups.

It would be easier for businesses to cooperate with infrastructure owners, and also for infrastructure owners to cooperate with other infrastructure owners because the tools and affordances needed for the integration of services and capabilities would already be there. Through the easier cooperation, and the possibility to build on existing infrastructure, the ability of businesses operating in a city to develop new services that would make them relevant, and which they could profit off of, would increase. By making it easier to create new services for the city, innovation would also increase.

8.6.3 Benefits for citizens

Citizens of a city with platformed infrastructure would greatly benefit from the innovation that would be made possible. However, this would not be related to the actual development of platformed infrastructure, but rather it would be because of the increased innovation and service development that results from platform infrastructure development. This is because most citizens would not want to develop their own services or functionality on top of the infrastructure in the city. Regular people will still not think much about the infrastructure that supports their lives, and only notice it when it does not work.

However, as the development of infrastructure as platforms would increase the adaptability of the infrastructure in the city, reduce cost for developing new services, and fuel innovation of new services, this has the potential to generate services that the citizens can use to increase their quality of life, improve the environment they live in, and allow the municipality to spend more money in other areas, because of the money they can save by the increased reuse of infrastructure capabilities.

Examples are the way in which neighbours of sports arenas would experience reduced light pollution because the lights in the sports arena would only be turned on when it is in use. It would give citizens a slightly easier life to not have to report electricity consumption manually, but could potentially have a great impact on the life of the citizen through home automation, and a more robust electricity grid, where the grid owner could fix errors more quickly.

8.6.4 Benefits for city development as a whole

In general, as has been discussed in previous sections and above, the city will greatly benefit from the increased innovation that infrastructure with a platform architecture can support. As per Caragliu et al.'s (2011) definition, investment in infrastructure in smart cities should fuel sustainable economic growth, increased quality of life, a good management of natural resources, and/or participatory governance. A city built on platforms, where it is easier for businesses and infrastructure operators to cooperate, and where accessibility to the platform infrastructures of the city is a focus area, will to a greater degree allow for infrastructure to be used in new and novel ways to solve problems related to air quality and environmental issues, allow businesses to develop innovative services that can generate economic growth, and increase the quality of life for citizens, and allow for better use and management of resources.

As an example of an innovation resulting from such innovative use of infrastructure, there is currently a project ongoing in Oslo where Telia, a cell phone operator, are cooperating with Urban Infrastructure Partners, who runs the network of rental bikes in Oslo (called Bysykkel), and the Norwegian Institute for Air Research (NILU) [9] to measure the level of air pollution in Oslo in real time[10]. Telia supplies the air pollution sensors, and the data connectivity needed to send data from the sensors to the servers where it is being analysed. The sensors are placed on the bicycle racks where the rental bikes can be picked up and delivered, and the data from the sensors are analysed using models that are created by NILU.

The goal is to create a real-time map of the level of air quality in Oslo, that can possibly be used by the citizens to avoid places in the city where the air quality is especially bad, or alert people with asthma or other allergies to stay indoors if the general air quality level is too bad, which in Norwegian cities often happen during the winter. All of this is a result of cooperation between three different actors with their own infrastructures, that combine features from their infrastructures to create something that none of them would have been able to do on their own. By combining the resulting information with even more data sources or infrastructures, there could potentially be even more use cases for this project. Oslo Municipality could use historical air quality data together with other data they have for the city to predict with more certainty which days will be extra polluted, and start preventive measures. They can also use information on which roads that are especially polluted, and start diverting traffic elsewhere to reduce pollution in certain areas. Another use case for the municipality could be to use the data to get a better way to see if their measures to reduce air pollution actually works. In essence, combining functionality and data from different sources and infrastructures opens up a broad range of new services and possibilities that would not have been there without the combination, and

[9] Norwegian: Norsk Institutt for Luftforskning
[10] https://teliasoneranorge.github.io/showcases/cleanair/

creating an infrastructure in a city where this combination is made easy by design, can greatly increase the amount of innovation that will occur.

All of these benefits for city development are, if one looks at a city through the lens of assemblage theory and information infrastructure theory, capacities that already exist within the city. However, as they are capacities that depend on interaction between the components that they exist in, they will remain unexercised and hidden until this interaction takes place. By building platforms, that are designed to interact with other components, the possibility for these capacities to emerge from the interaction increases.

8.7 Platform opportunities for Hafslund Nett, DLC and eSmart Systems

As I have described potential possibilities and opportunities with developing infrastructure as platforms, I will now describe which possibilities DLC and Hafslund Nett see in developing their infrastructures in this way, as well as look at some of the ways in which the effects of platform thinking has already been demonstrated by some of the projects eSmart Systems has worked on. The discussion in this section is based on the interviews done with the respective companies, as well as analysis of web pages and other material made available either publicly or by my sources.

To begin with, neither DLC nor Hafslund Nett currently sees their infrastructure as platforms. When asked about it in the interviews, representatives of both companies at first thought of IT platforms to program on, like Facebook or Android, and server infrastructure as a service, such as Microsoft's Azure or Amazon's AWS. Infrastructure as a service (IaaS), or cloud computing as it is also called in some cases, is a good illustration of how developing infrastructure to function as a platform can work. IaaS providers build server parks and IT infrastructure that is available for rent, as well as services built on top of their server infrastructure. Companies that need servers and IT services for their products can buy the processing power, and to some degree software, they need as a backbone for the infrastructure or service they want to build.

8.7.1 Hafslund Nett

Hafslund Nett mentioned several opportunities in the interviews with them, where there are services that they want to be available in their infrastructure, but that they cannot or do not want to build themselves. The possibilities and opportunities that were mentioned were firstly that of aggregators, where a company can gather several electricity consumers and act as one large consumer in relation to the network operator. Secondly, the possibility of using dynamic pricing that was automatically sent out to the customers, and using this to incentivise the customers to spend electricity in a smarter way was one of the main reasons for the implementation of AMS. In relation to this, the need for home automation systems building on information from AMS was also identified. I will go through these in the following paragraphs.

8.7.1.1 Aggregators

One service is what was called Aggregator by Hafslund Nett, and which is called Energy Service Company (ESCo) or Smart Energy Service Provider (SESP) by others. This was briefly mentioned in section 8.6.1. The function this company has is to recruit multiple electricity consumers to act as one in certain regards in relation to the network operator. Imagine a situation in which the electricity grid is being overloaded because it is an especially cold day for instance, or because production is lower than usual that day. The electricity grid operator has to cut the amount of electricity that is being used by customers, to make sure nothing goes wrong.

Currently, the grid operators have deals with large, industrial customers that tax the grid with high loads, such as factories. The grid operator can send a message to these factories in case of high loads, and tell them that their electricity will be cut for a period of time until the problem with high loads is reduced. The industrial customer is compensated for this inconvenience by paying less for electricity consumption than regular customers do. The role that an aggregator will fill is supposed to allow the grid operator to use regular customers in the same manner. The problem with this today is that the individual consumption of users is so small that it would have no effect. The aggregator will create deals with the grid operator on behalf of the customers, and install technology for controlling, as an example, their water heaters. If the grid operator then needs to cut consumption, it can send a message to the aggregator, which will turn off the water heaters of the customers it has agreements with. The aggregator can then get a monetary compensation from the grid operator, which will be distributed to the customers whose electricity was cut. This could potentially work the other way around as well in the future, as small-scale electricity production like solar panels on houses and small wind turbines are becoming more normal. The aggregator could make an agreement on behalf of the customers of producing electricity when Hafslund Nett sees a need for that.

8.7.1.2 Home automation systems and incentivising change in consumer behaviour

One of the main reasons behind AMS was that the parliament wanted the grid operators to be able to move the consumption peaks of electricity during the day, and even them out. The reasoning behind AMS's part in this, was that the decision makers thought that if you could make it cheaper for customers to use electricity during the times of day when there was a lot of free capacity in the grid, and more expensive during the hours of peak load, the economic incentive to use electricity at other periods throughout the day would be enough for people to change their consumption patterns to move the peaks.

A prerequisite to being able to implement this model of price fluctuations is that consumers need to be billed according to a continuously changing price that is used to incentivise them to use electricity when it is cheap, and not use it when it is expensive. With the old, mechanical power meters, consumers reported consumption once a month and would pay based on an estimate of the average electricity price for the month. With AMS, electricity prices can be dispersed electronically to the smart meters, and they report consumption to the concentrators they are connected to at relatively short intervals. As a result of this, it will become possible to send price signals to customers that could theoretically change their consumption patterns.

However, Hafslund Nett, other power grid operators, and some researchers have concluded that the price signals in and of themselves will not be enough to make people use electricity at other times of the day (Godbolt, 2014; Lie, 2016). The main reason that has been discovered is that electricity is so cheap in Norway, that the amount of time and effort needed to save relatively small amounts of money is not worth it for a majority of consumers. These issues were also brought by the representatives from Hafslund Nett during my interviews with them. They believe that home automation systems can be a help in this. If a home automation system can, based on price information from Hafslund Nett, as well as preferences set by the owners of the house automatically turn on the water heater or washing machine when electricity is cheap. This has also been pointed out in a recent doctoral thesis (Lie, 2016). Hafslund Nett does not want to start investing in and delivering the systems and hardware needed for this, and to a certain degree cannot, for the same reasons as for the aggregator role; the Norwegian and EU governments want grid operators to have as little contact as possible with customers.

8.7.1.3 Summary

Both of the benefits described here – aggregator and automatic home control – are examples of services that would greatly benefit Hafslund Nett in their daily operation of the electricity grid they own, and that would help them reach some of the goals of introducing AMS, such as evening out the consumptions peaks and allowing for easier electricity production from solar panels on the houses of individual customers. These functions are needed for AMS and the modern smart grid to be as effective as they can be, but Hafslund Nett does not or cannot build these functions themselves. Through developing the infrastructure they operate with a platform architecture, it would be a lot easier for third-parties to create these solutions and build them on top of Hafslund Nett’s infrastructure.

8.7.2 Datek Light Control

Just as Hafslund Nett, the representative from DLC also mentioned several opportunities and possibilities in the DLC interviews, that they could see by allowing their infrastructure to be used as a platform. The first one is the possibility of allowing others to use their communication infrastructure. Secondly, they see opportunities of combining their infrastructure with others to for instance only light up areas where there are actually people. Thirdly, they see possibilities of new ways of turning light on and off when it is needed by people, for instance by building applications that consumers can use, and lastly, they see that the data generated by their infrastructure can be beneficial to others. These will be described in greater detail below.

8.7.2.1 Shared communication network

The first possibility mentioned by DLC was the fact that their communication network would be able to carry other data loads than the information and control data sent to and from the lights and gateways. This is already being done; DLC has connected a ZigBee node to the water pumps in Maridalsvannet, which is Oslo's main source of drinking water. These pumps are being controlled by a system operated by the municipality, but the data to and from the pumps go through the same network DLC uses to control lights in Oslo. This is a small scale use of the network for other purposes, and DLC sees the opportunity to both allow other systems to transmit their messages through the network to separate backend systems, but also to send data to DLCs own backend system, that could be developed to control other systems as well, such as garbage collection.

The thought behind this is that DLC has built a well-functioning network that can connect different outdoor hardware via concentrators to a backend server, that could potentially have many uses outside of light control. This network is already built out in many urban areas, and the backend server is already created to be able to control different hardware based on sensor input and other rulesets. It would be relatively simple to adapt the server to be able to analyse other types of data, and control other types of hardware, and the network is already so general that it can transmit whatever data is sent to it.

8.7.2.2 Combined infrastructures

Secondly, they see the opportunities that can arise by connecting their infrastructure with someone else's. An example mentioned during the interview was the possibility to connect the light control system with data from telecom operators base stations. These base stations know how many phones are connected to them, which means that they can give an estimate of whether there are people in its area. DLC sees the potential to for instance turn lights automatically on and off based on whether the base station reports that there are people in an area or not. This is once again an example of how emergence through the easy combination of components to allow their hidden capacities to be exercised can be positive for infrastructure development.

8.7.2.3 Innovative light control

Thirdly, they see opportunities for innovative control of lighting (and potentially other systems if their infrastructure is used for those). Mobile applications could be used for this for instance. An example of this was also mentioned during the interviews; in winter, ski trails are prepared several areas for people to ski on. Some of these trails are called light trails[11], and they are lighted in the evening and night to allow skiers to easily use the trails when it is dark.

The example mentioned by DLC during the first interview here is that it would be possible to create an app where, when someone wants to ski in the evening or during the night, he or she can turn on the lights with this application. Then, through using the GPS on the skier's phone, the lights in the area where the skier is at any given moment could turn on, and off again when the skier has moved on so that the light follows the skier around the trail. This would save electricity and reduce lighting pollution, as there are many hours of the night where the lights are on, but where there are only a few or no skiers on the trail. This, and

[11] Norwegian: Lysløype

other innovative solutions like it, could potentially be created by third parties, building on the infrastructure created by DLC.

8.7.2.4 Data sharing

Lastly, DLC sees the possibility that others could make use of the data generated by their infrastructure. The lux meters mentioned earlier, that measures the amount of luminance in an area and is used to turn a light on or off based on whether it is dusk or dawn, was one of the possible useful data sources that they see in their infrastructure. Another was the position of light fixtures, as many of these report their location through GPS. There are possibly other data sources that could be useful for others as well, because of the hidden capacities to interact with other components that lie inherent in these data components. Both the examples listed here and the ones described in the section on combining with other infrastructures are examples of emergence of new capacities to interact between components that are only visible when the interactions are made (Henningson & Hanseth, 2011), as was described in the introduction to information infrastructure theory.

8.7.2.5 Summary

The above paragraphs describe both possibilities that would benefit DLC directly through more or better services in their infrastructure, and also possibilities where others could benefit from the infrastructure DLC are operating, and where the benefit for DLC itself is mostly the possibility of generating income by letting others use their infrastructure. The examples of combined infrastructures and innovative light control are instances where DLC would benefit directly, because these would make the product they deliver more feature-rich, and it would give them a possible edge over competitors by being able to deliver for example the solution for evening skiers where they can be followed around the ski trail by light. These solutions would be more easily attainable if the infrastructure is built as a platform, because the interfaces to build them on top of the core infrastructure would already exist, and because the infrastructure would be designed to be extended by third parties.

The example of shared communication network is an instance where DLC can get direct benefits because it would make them a suitable supplier of a smart city communication network, which is a selling point, but it is also an instance where it would benefit third-parties that would not have to create their own communication network, and could buy the service from DLC. Once again, this would be facilitated by developing the infrastructure as a platform, because the network would by design be possible to open up for third-party communication. The last example of data sharing is mostly an opportunity for DLC to make money or other benefits by allowing third-parties to use capabilities they have already built in their platform core.

8.7.3 eSmart Systems

With eSmart Systems, the purpose of the system they are developing is to connect capabilities and data sources from different systems, to enable new functionality and new capabilities that did not previously exist. The opportunities they see lie in the fact that both within businesses, and between businesses, there are several separate systems that do not communicate, but that could benefit from having their data and functionality connected. Below are listed some examples of what eSmart Systems are doing today, and/or plan on doing in the near future. These examples are firstly a system for emergency rooms that combines data from several health care departments. Secondly, eSmart Systems sees possibilities with the role of aggregator just as Hafslund Nett does, and also sees great possibilities in making it possible for consumers to generate their own electricity through solar panels, as well as home automation systems that can utilise the electricity in a smarter way.

8.7.3.1 Emergency room system

To start with an illustrating example, eSmart Systems has cooperated with a municipality in Norway on delivering a system for their emergency room. The new thing about this system was the fact that it connected data from systems from the emergency room, the ambulance service and the home health care service. Imagine an elderly patient calls into the emergency room and needs help.

The emergency room staff will then dispatch a message to either the ambulance service or the home health care service, or both so that the medical staff in those services can help the patient. Usually, these three departments of health care have their separate journal and logging systems. That means that if the same patient calls into the emergency room a little while later, the staff there are not able to see what happened to the patient or which actions were taken the last time the patient called. The only thing they would see would be that the patient had called them a few days ago and that the call had been sent on to another department. With the new system from eSmart Systems, all these medical departments can now share information and logging between them. This allows all of them to give better answers and help to people calling in, as they can see their complete history with the health care service in the municipality, rather than just the one department they are speaking to at the moment.

Another benefit that was introduced with this system, was the ability for health care staff in the emergency room to connect data from GPS tracked dementia patients, together with the location of next of kin and ambulances, so that if a dementia patient wanders off, they can send a message to the person or ambulance that is closest to them to pick them up.

8.7.3.2 Aggregators and local electricity production

eSmart Systems also sees the benefits of the aggregator roles that were introduced in the earlier section on the opportunities seen by Hafslund Nett, where one company acts as a large electricity consumer on behalf of several regular consumers in relation to the power grid company. In addition, they see the positive sides of allowing electricity consumers to produce and sell electricity from their own small-scale production facilities. eSmart Systems sees this as an opportunity for them to develop a system that can help both grid operators and prosumers (consumers that also produce) connect their systems, and the server infrastructure needed for aggregators. In many ways, eSmart Systems' business is built on the idea of connecting systems within a business, sector or public body, or in-between those entities, to allow for the capabilities and data inherent in and generated by the different infrastructures and systems to work with each other to create new value and new functionality that was not there or usable before.

The possibilities and benefits listed above, serve as real-world examples of the opportunities that arise from developing infrastructure as platforms. This is not to say that the opportunities described would be impossible to do without developing infrastructure with readily available interfaces. However, the point of the above sections is to describe the opportunities and benefits real companies see building services, infrastructure and systems on top of their infrastructure. I have argued in the earlier sections on smart city challenges, information infrastructures and platforms, that developing infrastructure as platforms would make creating this kind of service that builds on existing infrastructure easier. In that way, the examples listed above serve as illustrations that there are real problems and business opportunities that could be simplified and made easier to solve by developing infrastructure as platforms.

Both of the examples described above – and most products from eSmart Systems – are examples of them building software and server infrastructure that can be very helpful for infrastructure owners that want to develop their infrastructures to become platforms. The opportunities described here serve as examples of what third-party companies could deliver to infrastructure owners; smart solutions that build on the core infrastructure components, and as complementary components add functionality that enhances the infrastructure.

8.8 Summary

In the sections preceding this point in the thesis, I have discussed the challenges facing the development of smart cities today, that have been identified in research around smart cities. These include a lack of a holistic development focus from city administration (Cocchia, 2014), a tendency to focus on either hard (infrastructure) or soft (education, values and business) smart city development (Neirotti et al., 2014), and a tendency for smart cities to develop as a result of separate, independent projects without a lack of central control (Cocchia, 2014; Neirotti et al., 2014). I have then argued that the development of infrastructure is important because a city needs to be backed by an infrastructure that can support the services and values that city planners want to develop. Subsequently, I have discussed how infrastructure in a modern smart city needs to support innovation and quick development of new services, and that one way to achieve this would be to develop the infrastructure to include generative mechanisms that increase the level of and ability for innovation. Further, I have argued that this can be done by developing the infrastructure using a platform architecture because this kind of architecture emphasises generative traits. I have then discussed some theoretical and real-world opportunities and benefits of developing the infrastructure of smart cities in this way.

Chapter 9 Developing platforms in smart cities

I will now continue by discussing how infrastructure owners and local, regional and national administrations can go about developing the infrastructure they control into platforms. I will start at what needs to be done from the perspective of infrastructure owners, as this is where the actual development of infrastructure happens. I will then move on to discussing how the government can incentivise the owners of infrastructure in the direction of platforms.

9.1 Developing platforms for infrastructure owners

As discussed in the section on platforms, there are two prerequisites for infrastructure to be developed as platforms; the first prerequisite is IT capabilities that allow for monitoring of the infrastructure and data gathering, and control mechanisms to be able to remotely and automatically control parts of the infrastructure. As an example, consider DLC's system that gathers data on the environment such as lighting condition, and light status, and can turn the lights on and off remotely and automatically. The second prerequisite is that a platform infrastructure needs interfaces that allow outside components to connect with the data and capabilities inside the core infrastructure.

9.1.1 Introduction of adaptable IT capabilities

As the interfaces need to be able to connect with the IT capabilities, the first step for infrastructure developers would be to make sure that these capabilities exist in their system. As mentioned earlier, this is something that most infrastructure already contains. It has been discussed extensively how the introduction of information technology has entered into most areas of society, and how ubiquitous IT systems have become. This holds true for critical and other public infrastructure as well, as the introduction of monitoring and control systems have made the job of maintaining and operating infrastructure easier.

However, as most of these systems that are already in use were introduced for the purpose of monitoring and controlling the infrastructure, they could possibly be limited in which data they gather, and which functions they can control. A challenge for the infrastructure operators would then be to examine the system they operate and look at which types of data it produces that they maybe do not collect at the time, but that could be useful for other applications than the ones they are concerned with at the moment. The same goes for control systems, as there may be some functionality that is not useful for the operation of the infrastructure as it is today, but that could potentially be utilised by others.

To recap the definition of generativity, generativity is the function of a technology's capacity for leverage across a range of different tasks, adaptability to a range of different tasks, ease of mastery, and accessibility (Zittrain, 2006). As the infrastructure should be adaptable to different tasks to be generative, I believe it would be an important point for infrastructure developers to design their infrastructure and monitoring systems in such a way that it would not be overly complicated to start collecting a new type of data, from a new part of the infrastructure. In other words, the systems used for monitoring and control should be as generalised as possible, so that they are easily adaptable, rather than very specialised. Of course, there are different demands for different kinds of and parts of infrastructure. Some monitoring and control systems need to be specialised and separate from others, either for practical or security reasons.

The argument I am making is not that this should be done regardless of other considerations. However, I believe that the general rule of developing infrastructure should be to build them in such a way that they would be easily adaptable to new situations. Systems like the platform built by eSmart Systems could be part of the solution here. Because the installed base of monitoring and control systems in existing infrastructure is separate and specialised in many cases, and because it also in many cases could be beneficial to keep them this way, and develop new ones in the same way, a system like the one developed by eSmart Systems where the systems can be connected, and where new systems and data sources can easily be added would serve the same purpose as having a generalised monitoring and control system.

Another point, with regards to infrastructure operators looking for opportunities to control and monitor parts of their systems that they are currently not doing that for, is that there, of course, are other considerations to be done here as well. Some data should maybe not be collected because of privacy issues, such as customer information, or usage information that could identify individuals. Some functionality should probably not be controllable remotely, because of security issues. For instance, it should probably not be possible to turn the electricity in Oslo off over the internet (and there are rules against connecting this functionality to the internet today in Norway). So to sum this up, in general systems should be built to collect and monitor data easily, and to easily be controllable remotely, but this is not a one size fits all solution, and concerns such as privacy, security and efficiency must of course also be considered.

9.1.2 Introduction of interfaces

The second prerequisite, that the infrastructure needs interfaces for outside components to connect to, also needs to be the rule in infrastructure development. How these interfaces should be built would also, of course, be different from system to system, and the development would be subject to the same concerns listed above. As the internet is a well-established de facto standard for communication between heterogeneous networks, IP-based interfaces can be a good way to develop the connections in general. This is a view that is held by DLC. During one interview, the representative discussed how they thought it would be impossible to develop communication standards and networks that would be able to work with every single aspect of the modern smart city. Instead, DLC holds the belief that different systems should use the communication infrastructure that is most suited to their needs, and integration should happen over the internet.

In the case of AMS, Hafslund Nett have decided to use the HAN port as the designated interface for external use. The HAN-port was discussed in the introduction of AMS earlier in this thesis and is an RJ45 port on the smart meter, that continuously sends out the data registered by the smart meter. This was chosen by Hafslund Nett because it is a proposed standard by Norsk Elektronisk Komitè[12] for extracting data from a smart meter. They chose not to create another interface where information for multiple customers can be extracted, because of the previously discussed wish of having as little contact with consumers as possible.

If Hafslund Nett were to distribute usage data to for instance aggregators on behalf of consumers, they would have to take care of consent and would, therefore, need to have an agreement with the customer. Another positive thing about this is that it could satisfy some privacy issues. If the only interface available for extracting electricity consumption data consists of a physical port on every person's smart meter, the threshold for extracting this data for malicious purposes are raised, as one would need physical access to the port to be able to do it. This shows both that there are valid reasons for creating other kinds of interfaces and is an example of an interface that can be made that functions in another way than IP-based interfaces.

9.1.3 Allowing others to build on the platform

Although not a prerequisite for being architecturally a platform, it is important with regards to maximising the generative potential in an infrastructure that tight control is not held over who or which organisations get to connect to and develop on top of the platform. In platform theory, a great deal of the innovation on platforms comes from the fact that several independent actors are allowed to more or less freely build on the infrastructure in the core, as long as they follow the rules of the platform owner (Tiwana, 2013). This free flow of development allows for the generation of ideas from multiple entities, rather than just a select few which the platform owners deem worthy of development, which can mean greater innovation.

In information infrastructure theory, a clear mechanism behind how information infrastructures evolve is a tension between stability and change in components

[12] The norwegian branch of IEEE

(Hanseth et al., 1996). Too tight control of who can develop what on the infrastructure can limit the change part of the equation, which leads to stagnation and little development of new services and new usage of the infrastructure. In this regard, it is still, of course, an important point that some parts of infrastructure that can potentially be opened for third-parties to develop on, should maybe not be opened to allow anyone to develop on top of them for security or privacy reasons or other considerations.

9.1.4 Summary

The arguments in the above paragraphs are as follows; city infrastructure needs to have IT capabilities that can monitor and control the infrastructure, and interfaces to connect to these IT capabilities for outside users of the infrastructure affordances. This means that in infrastructure where IT monitoring and control systems do not exist, they need to be added. In these cases, efforts should be made to introduce generalised systems that make it easy to add other monitoring and controlling capabilities in the future, if the need arises. In cases where these capabilities already exist, and after they have been introduced in systems where they did not exist, interfaces to connect to these systems from the outside needs to be created, to allow for reuse of capabilities from outside components.

In all cases, efforts should be made by infrastructure owners to identify possible capabilities and data sources in their infrastructure that it would not make sense to gather and control for monitoring and maintenance purposes, but that could be useful for other entities. They should also build their infrastructure, IT capabilities and interfaces in such a way that they are easily extendable to account for new situations and tasks that could arise in the future. While doing this, infrastructure owners should of course also take other considerations like privacy and security into account, so that the possibility of reusing infrastructure functionality does compromise societal security or civil rights. It is also an important point that the strictness of who gets to develop on top of the infrastructure is as open as possible, to not restrict innovation just for the sake of keeping control where it might not be needed.

9.2 Governing infrastructure development as administrators

After discussing what could be done by infrastructure owners and builders to develop infrastructure as platforms, I will in this section discuss how national, regional and local administrations can use their mandate to govern the way in which infrastructure is developed. The organisations that develop infrastructure are the ones who have to do the actual changes to infrastructure. But as discussed in the section on platforms earlier in the discussion, most if not all nations of the world holds control over how public infrastructure is developed, and because of this have a position to influence in what way the infrastructure organisations develop their infrastructure. This means that the governors of a country or city have a responsibility and possibility to use their position to make sure that the public infrastructure in that country is developed in a way which is best for the society it builds up under.

9.2.1 Use infrastructure ownership and control to steer development

If one accepts the arguments that infrastructure in a city should generally be cultivated in the direction of becoming platforms on which others can build their services, then a task for legislators is to incentivise and govern public infrastructure to evolve in the ways which were described above in the section on what infrastructure owners must do. The mechanisms through which legislators can do this was discussed in the section on infrastructure development in smart cities, but I will briefly go through them once again now.

In Norway at least, the state owns much of the public infrastructure, as does counties and municipalities. In some cases, infrastructure is fully owned while in others the companies that develop the infrastructure is owned in part by the government. In all cases, also the ones where infrastructure is not owned by national bodies, there are laws and regulations that govern minimum quality standards, business practices and in some cases (like for electricity grids) the amount of money that can be asked for from customers. As was also discussed in the section on infrastructure development in smart cities, in the cases where infrastructure or services are bought in from contractors (like what is mostly the case with the lighting infrastructure DLC operates on), the call for bids from contractors come with a list of demands for which features and minimum requirements contractors are expected to include in their bid. All of these tools can be used to direct the development of public infrastructure towards platforms.

9.2.2 Suggestions for what to demand

How to structure these laws, rules, regulations and demands lies within other knowledge domains than my own, and I cannot suggest any concrete actions that should be taken based on the research I have done. However, I can list some suggestions for what should be regulated and which demands should be made from a technical standpoint, and based on the research I have done;

Firstly, in those infrastructures where it is not already the case, the state should demand that monitoring and control systems be introduced. I do not know if it is the case that these are absent from any important infrastructure, nor do I know the status of laws regarding this, but to the best of my knowledge, this should be introduced as a general demand for all infrastructure if it is not already. This demand should also include the need for systems that are as adaptable as possible to include new functionality. Secondly, there should also be a rule that states that in general, interfaces for connecting to the functionality of an infrastructure should be developed. Thirdly, infrastructure operators should be expected to – in general – open these up to a great degree, and as far as possible allow anyone with interest in it develop on top of the infrastructure through these interfaces. The ability to restrict access to these should be kept to a minimum, and only be allowed when concerns like privacy or societal or national security are deemed to be more important.

As for rules for specific implementation details for the different IT capabilities and interfaces, it would probably be hard to create comprehensive standards for all of the different kinds of interfaces that would need to be made. It has also been discussed within information infrastructure research that performing large-scale standardisation processes tend to increase in scope, and become unwieldy. Hanseth and Bygstad (2015) suggests that the method of flexible generification, where only the parts of an infrastructure that absolutely must be standardised is standardised, and other parts are standardised as the need arises, often becoming de facto standards. However, in the interest of keeping the ability to connect to the platform for anyone as open as possible, there should be regulation in place keeping infrastructure owners from preferring proprietary, expensive interfaces. They should be encouraged to utilise open standards, or at least be required to release the specifications for proprietary solutions.

9.2.3 Clarify data ownership and possibility of use

Lastly, there was one concern that was brought up in all interviews with all three studied cases; it is in many cases unclear what they are allowed to do with the data they generate, and who owns it. I have mentioned earlier that there are rules in Norway stating that all public data should be made available in machine-readable formats. The representative for DLC, however, took up the issue that it is not necessarily clear what constitutes public data. An example was brought up with the location of the lights on the infrastructure DLC operates. In many cases, the light control unit includes a GPS chip, so that the LCU can report where it is positioned to the backend server. This could be public data, and could potentially be information that is of interest to some third party. However, the representative from DLC was not sure if this is public data and if it is, whether they can distribute it without first speaking to Oslo municipality, or other customers if the lights in question are not Oslo's. In general, it is unclear whether the data generated by DLC's light control infrastructure is owned by DLC or the customer that have bought the infrastructure, and it is not clear whether this should be seen as public data as it is generated by public infrastructure or not.

Hafslund Nett had other concerns more related to privacy, where it is unclear which data they are allowed to use for which purposes. As discussed earlier, The NDPA are sceptical of allowing grid operators to use consumption data for anything other than billing, at least without explicit consent from users, while Hafslund Nett and other actors have other uses that they would like to be able to use the data for. The question of what the data can be used for is also here related to who actually owns the data, the customers it is generated by, or the companies that operate the infrastructure it is generated by. These issues should be clarified to make it easier to know what to do in situations like this.

9.2.4 Summary

As a summary, regulators and lawmakers should use the tools at hand, such as laws, regulations, ownership and bidding processes, to incentivise and require that infrastructure be developed to include IT capabilities and interfaces, given that one agrees that platform architecture is a good way to build infrastructure. The tools available should be used to require that the IT capabilities are developed in a way which makes it easy to adapt to new uses, as well as require open and to a large degree standardised interfaces. In general, infrastructure owners should be incentivised and required to allow mostly anyone who wants to connect to the interfaces that are made, to build on the infrastructure, within reasonable boundaries. As I have argued for which steps need to be taken by infrastructure owners and regulators, I will move on to discussing challenges with developing the infrastructure in this way.

9.3 Challenges in platform development

In this section, I will go through the challenges pertaining to develop infrastructure as platforms. I am going to begin by discussing how needs like privacy and security has to be addressed. I will then go on to discuss how the market mechanisms that govern platforms as market structures, and which issues could arise from the fact that infrastructure is mostly monopolies. In relation to this, I am going to discuss how negative or a lack of incentives can affect the development. The discussion will turn to the need for server infrastructure, and how this could potentially be problematic.

9.3.1 Challenges to safety, security and privacy

As society is dependent on the infrastructure that underpins it, it is indisputable that keeping infrastructure safe and in working order is imperative for individual, societal and national security. Given this situation, it is natural that infrastructure building organisations, as well as governments, would lean towards keeping a great deal of control over who are allowed to interact with the infrastructure, and in what way. To reiterate an example used previously, there are strong arguments for why automatic control systems in the electricity grid should not be connected to the internet for instance because this would be a security risk as hackers could potentially be able to shut down the electricity of an entire region or even country.

There is also an issue with privacy, as data such as electricity consumption information on an individual level could be used to determine whether a person is at home or not for instance. eSmart Systems mentioned the possibility of using water and electricity consumption data in conjunction to determine whether an accident had happened in someone's home, or to prevent accidents like floods and fires. While this sounds like a good thing if the data is only used in this benign way, this opens the possibility for surveillance of individuals, that could be dangerous and a serious invasion of privacy if it ended up in the wrong hands. The best way to ensure that this kind of data does not fall into the wrong hands would be to make sure that it cannot be extracted from the system that collects it. This would be challenged by developing infrastructure as platforms, because in general data should be made available, and the development of interfaces would increase the probability of the introduction of a security hole that allowed extraction of data that should not be possible to extract.

This ties into the bigger discussion on how the collection of large scale data can be a privacy and security issue, even without the risk of the data being extractable outside of the infrastructure that generates it. There has been some discussion around the fact that Hafslund Nett and other grid operators are storing consumption data for each individual terminal point for several years, much longer than the time needed to use the data for billing. The Norwegian Data Protection Authority[13] (NDPA) are critical of this and holds the view that individual consumption data should only be available for billing (Datatilsynet, 2010). A representative for Hafslund Nett, however, suggests that they need the data for planning purposes. By being able to look at historical consumption data on an address, they can be better able to decide which upgrades would need to be done on the electricity grid serving that address in the instance of a change to the building, or an anticipated increase in consumption.

The representative's argument for why this usage and storing of individual consumption data is unproblematic was that Hafslund Nett was not going to use the data for anything else, nor make it available. While there is no reason to doubt that this is true now, the fact this information is available is a privacy risk in itself, because as long as the data exists, there is a risk that it falls in the hands of someone who should not have it, who could use the data from anything from advertisement to mass surveillance.

While I discuss this with an example from Hafslund Nett, this problem holds true for any system that collects large amounts of data that could be used to identify and monitor individuals. In summary, great care needs to be taken to make sure that privacy and security are not compromised while the infrastructure is developed to be more open and easily connected to from the outside. This means security in the sense that critical infrastructure functions should not be possible to tamper with by outside actors, but also that private information is kept safe. The same applies to privacy, and on the subject of privacy, it is important to discuss the mass storage of information on individuals, as the existence of that data poses a privacy risk in itself.

9.3.2 Platforms in a governmental and monopoly environment

Platforms as market structures develop because of the formidable benefits that are granted to all sides of the market that are being platformised (Tiwana, 2013).

[13] Norwegian: Datatilsynet

As was discussed in the introduction on platforms, the benefit of platforms in a competitive market situation is that network effects gives both developers and users a reason to invest in the platform, which earns the platform sponsor money (Tiwana, 2013). This effect is part of what incentivises companies or networks of companies to develop platforms. As they operate in a competitive market, they need to make sure that their platform is accessible to both users and developers, and attractive and easy to use, as both these groups would leap to competitor's platforms if alternatives that better cater to the needs of the groups appears.

These incentives are lacking from infrastructure development, as most infrastructures are natural monopolies, and companies operating public infrastructure mostly do not compete with other infrastructures. There are a few exceptions in Norway, such as mobile phone operators and broadband network operators, but roads, electricity, public transport and public lighting, for instance, do not have other infrastructures that they need to compete with. As the user groups of consumers and (potential) developers do not have a choice of which infrastructure platform to develop on, the incentive to work hard to create adaptable and easy to master interfaces does not exist to begin with. This can be mitigated by creating regulations and quality standards that the infrastructure owners must abide by, but this is not necessarily an incentive that will make infrastructure owners reach further than the minimum requirements.

Another problem is the fact that infrastructure owners should not be able to make a lot of money off of developing the infrastructure as a platform. While some form of economic incentive to allow others to build on your platform is probably something that is needed, as consumers would have to foot the bill of developing the interfaces if the businesses that use them are not paying for them, there should probably be heavy regulation on how much the use of these interfaces is allowed to cost. I make that argument on the same grounds that the amount grid operators are allowed to take from consumers is regulated heavily; as infrastructure in most cases are natural monopolies, there are no market dynamics regulating prices.

The fact that there would be limited possibilities to profit from platform development could also impede the will from infrastructure operators to give third-parties access, as it is possible that the infrastructure operators see no upside for themselves in this transaction. In essence, there are market mechanisms that fuel the development and ease of use and accessibility of standards in a regular market environment, that are lacking from infrastructure development. This can be mitigated by government regulation, but it is not clear if this is enough to bring out the most of the positive effects that platform infrastructure can provide.

9.3.3 Dependence on server infrastructure

I will now turn to the need for server infrastructure. It is self-evident that adding large-scale IT capabilities to a large and complex infrastructure produces a need for IT infrastructure to underpin it. This includes servers that are used for data processing and storage, and as the central control units. During the last few years, there has been a revolution in how this server infrastructure is appropriated by companies and organisations. Where larger organisations previously had their own server parks where all their computing needs were located, and smaller organisations rented servers from what by today's standards were small data centres, mostly all organisations with few exceptions are utilising cloud servers. This is in many instances called Infrastructure as a Service (IaaS).

As previously briefly discussed, IaaS means that companies rent virtual or physical servers, as well as potentially algorithms or other software from companies that operate large server farms and data centres, instead of buying and maintaining their own hardware. All of the three companies I have interviewed for this thesis are utilising IaaS, and both Amazon Web Services (AWS) and Microsoft Azure are utilised by these companies. Both of these cloud service operators have large data centres in Europe, with both of them having locations in Ireland, Germany and England and Microsoft Azure having an additional data centre in the Netherlands (Amazon Web Services, n.d.; Microsoft, n.d.).

There could be a potential privacy and security risk with the fact that systems that are critical for important public infrastructure in Norway is run from servers physically located in other countries, as well as a potential problem that personally identifiable data is brought out of the country, and being potentially accessible by, and under the jurisdiction of, foreign governments. Response from representatives of the studied organisations, when asked about this, was that they had not thought much about these issues, but leant on current regulations regarding this in Norway, which allows for the use of cloud servers outside of Norway in most cases as long they are placed within the European Union.

I believe there should be a discussion on whether server infrastructure like this should be seen as important, critical infrastructure that the state should provide citizens and businesses, and if that is the case, whether one should make sure that this kind of infrastructure exists within the country, in the same way that it is deemed important for a country to have infrastructure in place for electricity production and distribution, or food production in the event of a crisis. To reiterate the discussion; server infrastructure is such a big and important part of society today, and would also be increasingly important in an environment where infrastructure should operate as platforms. While it is out of scope for this thesis, there should, in my opinion, be a discussion on whether server infrastructure should be viewed as important public infrastructure, and if so, whether steps should be taken to make sure that Norway is, for lack of a better word, self-sufficient with regards to server infrastructure.

9.3.4 Making sure everyone benefits from the development

There is a broader issue mentioned in some research on infrastructure, that in the cases where infrastructure is privatised and set out to be run by private companies, the level of quality for less wealthy citizens decrease, while those with an abundance of resources can pay for better service (Plantin et al., 2016). While the argument to develop infrastructure as platforms does not change anything in relation to this issue with existing infrastructure, there is a potential problem that the innovation that is done could be available for the rich or the tech-savvy, and not everyone. This is an issue already apparent in some smart cities, where a highly educated, young class of citizens gain a lot of benefits from the projects and outcomes that are generated from the smart city projects, while a large portion of the population is left out of the development, because of a lack of resources, a lack of technology knowledge, or other reasons (Hollands, 2008; Nam & Pardo, 2011; Neirotti et al., 2014).

Great care will have to be taken by city administration, as well as national administration to make sure that the innovation that is done on the basis of the existing infrastructure, and that will probably to a large degree be done by private companies or individuals, come to the benefit of all of the population in the city, not just a few. Once again this is an issue that is outside both the scope of this thesis, as well as my knowledge area, but it is a very important point to be raised in the development of smart cities and needs to discussed and mitigated.

9.3.5 Summary

As discussed in the paragraphs above, there are a lot of potential issues and challenges that needs to be addressed, both in relation to smart city development and infrastructure development in general, but also in relation to developing platforms especially. Great care needs to be taken when utilising new opportunities and new technology to make sure that there are no large adverse effects of the development.

Firstly, when connecting infrastructure to the internet, both the control systems of the infrastructure and the data generated are potentially vulnerable to attack from the outside. This poses both a security issue, where it is imperative to make sure that important societal infrastructure cannot be shut down for malicious purposes and a privacy issue because of the possibility for potentially sensitive personal data to be leaked into the hands of people who should not have them. In relation to privacy, great care should be taken to make sure that data is anonymised where it can, and not gathered and stored when their existence could form a large potential privacy breach.

Secondly, platforms have mostly arisen and exist in competitive environments, and many of the mechanics that have been explored and explained depend on this competition. To be able to build functioning infrastructure platforms that work to increase innovation in a city, one needs to find ways to replicate these mechanisms in an environment where there is little to no competition, and where the platform owners cannot be mostly motivated by earning money.

Thirdly, the need for IT capabilities in platforms, and the general ubiquity of IT in modern society has made server infrastructure an extremely important infrastructure that underpins important functions in very many infrastructures that are imperative for society to function properly. Care needs to be taken to make sure that this infrastructure can be relied upon in any situation, much in the same way as it is a national goal to be self-sufficient on electricity and food. There is also an issue in that data generated by Norwegian infrastructures, that can be sensitive information on Norwegian citizens are being stored on servers other places in the world. It has to be secured that this information is governed and controlled by Norwegian legislation.

Lastly, if not taken care of, there is a possibility that the benefits of developing infrastructure will only reach the ones with the resources or knowledge to benefit from it, and not those without. It is important that the national government makes sure that every citizen benefits from this new development.

Chapter 10 Conclusion and future research

In the following chapter, I will do a summary of my arguments and the most important conclusions that I have drawn. I will then go on to point out several directions where future research could clarify issues or questions that arise from the arguments that I have made.

Information infrastructure theory has been the theoretical framework used in this thesis. Emergence and generativity have been the two concepts that I have utilised the most throughout the analysis and discussion in chapters 6 through 9. Emergence is, in the context of information infrastructure theory, when components of the infrastructure combine in unexpected ways to create new functionality, seemingly without intent from any designer or user groups (Henningson & Hanseth, 2011). This emergence happens through generativity, which is a concept describing an information infrastructure's capacity to produce unprompted changes (Zittrain, 2006). The generativity of an information infrastructure is a function of its ease of access and mastery, and its adaptability and possibility for leverage across a range of different functions (Zittrain, 2006).

As stated in the introduction, and several other places in this thesis, the research question I have worked with is *how can knowledge from research on platforms be applied to the development of smart cities.* My main findings are that focusing on the development of infrastructure is important for cities that strive to become smart cities because the infrastructure has to able to support the smart initiatives of the city. This can be achieved by building the infrastructure using platform architecture because platform architecture can make the infrastructure more generative. Having a generative architecture can help support innovation in the city, and answer some of the challenges that are facing smart cities today. A longer summary of the answer to the research question can be found in the following paragraphs.

10.1 Platforms as answer to smart city challenges

There are several challenges with the way smart cities are developed today, as discussed in several research articles about the phenomenon (Caragliu et al., 2011; Cocchia, 2014; Hollands, 2008). While the reasons behind these issues and possible solutions for them are complex and diverse, I believe that focussing on the development of infrastructure in a city can help alleviate three of them, which are a lack of a holistic focus from city government, a focus that is either on hard (infrastructure) development or soft (education, safety, values) development, and a tendency that the city develops as a consequence of several unrelated projects.

I believe infrastructure focus will help alleviate these issues because infrastructure is the basis of most processes and activities that exist in a city, and they to a large degree shape and define which way a city can or cannot develop. By focusing on infrastructure that is easy to utilise in new and innovative ways, and that contains the capabilities one wants the city to have, this will in time influence the development of the city in the right direction. I further argue that a good way to do this is to develop the infrastructure in a city as platforms, because of the generative properties in platforms that will help increase the potential for innovation and innovative use of the capabilities that already exist in the city. I have also argued for why this would be beneficial for both infrastructure owners, businesses and citizens, and for the city as a whole. My first and most important conclusion is then that, based on the arguments throughout this analysis, developing infrastructure as platforms in a city will help develop the city as a whole to become smart, in accordance with Caragliu et al.'s (2011) definition. This definition states that a city is smart when investments in infrastructure along with human and social capital are made in a way that fuels sustainable economic growth, quality of life and a wise management of resources.

10.2 How to develop platforms

The way this needs to be done is to make sure all infrastructure in a city contains the IT capabilities needed to collect data from the infrastructure and to utilise the capabilities inherent in the infrastructure. It is then important to build interfaces through which third-parties can connect to and build on the data and capabilities inherent in the infrastructure, that it is sensible to expose to the outside. This will increase the level of and ability for innovation in the city, as anyone is given the possibility to build on existing infrastructure, rather than having to build their own expensive and time-consuming infrastructure.

While it is up to the organisations that build and operate the infrastructure to do these changes, it is important that national, regional and local administrations use the democratic tools they have available to incentivise and demand that infrastructure is developed this way. This is because the incentives to develop platforms are mostly market-driven, and most infrastructures are natural monopolies. This means that the government needs to take the role that the market mechanisms have in regular market-driven platform development to steer the development. The other reason that the government needs to take this role is that, if the argument that platform building is a good way to develop infrastructure is accepted, it is in the public interest that the infrastructure be developed in this direction, and it is up to the state as owners and regulators of public infrastructure to enforce this development.

10.3 Challenges in platform and infrastructure development

While this is done, there is a host of issues and challenges that need to be explored and solved. These are issues related to security and privacy, in relation to which it must be discussed which infrastructures and capabilities within infrastructures that can safely be exposed to outside parties, and what kind of data should be collected, as well as how it should be stored, and which uses it should be available for. It is also important to clarify rules about who owns the different kinds of data that are generated and has the right to decide what it can be used for. It is also important to make sure that the developments and innovation that emerges in smart city benefits all citizens regardless of education, social status or other characteristics so that the development fuelled by public infrastructure does not only cater to the wealthy or highly educated.

10.4 Future research

I will now point out some possible themes for future research, that I have found interesting while working on this thesis. As a first point, my goals with the research for this thesis has mostly been on exploring the opportunities and benefits of developing infrastructure in a city as platforms. While I have identified issues with doing this, they have mostly been mentioned more than explored, and a more critical examination of public infrastructure as platforms would be of interest, to examine the possible downsides with the approach, and discuss possible alternatives that could give the same benefits, but with fewer downsides. Another weakness with my discussion is that I discuss this subject on a rather theoretical level, where the conclusion gives rather broad, high-level suggestions for how city infrastructure should be developed. A study that would generate input on how to more concretely carry out this development would, I think, be interesting, as well as studies looking empirically at the effects infrastructure as platforms have.

In this thesis, the infrastructures that have been studied are lighting and electricity grids. In both these cases, I found benefits for the infrastructure owners and citizens, that suggest that developing the infrastructure as a platform would be a good idea. Although I believe this to be true for most kinds of infrastructure, this is also a possible area for future research; looking at how this development could affect other kinds of infrastructure than the ones I have studied. Lastly, I believe that all of the points discussed in the section on challenges could benefit from a study by themselves, as I believe both privacy and security to be very important concerns in the modern day technology driven world. Most of these points are important political discussions, but I think these discussions would benefit from a solid academic analysis of the issues.

Smart cities are here to stay, and so are the technologies that the smart cities will be built on. As I have discussed throughout the chapters in this thesis, developing smart cities can have both negative and positive consequences, and how the infrastructure of the city is developed and governed can have a great effect on how the city itself is developed. Because of this, it is important that researchers studying infrastructures engage in the discussion on smart city development and try to find out how to reinforce the positive effects that smart city development can have, and avoid the possible negative consequences.

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