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Smart City Platform Interoperability and Vendor Lock-In

How do smart city platform architectural factors contribute to vendor lock-in of smart city platform owners?

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Preface

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Executive Summary

The amount of smart city projects worldwide is projected to increase at a rapid pace, and these smart city projects must alleviate an increasing amount of urban problems. However, there are no clear standards for these smart city projects, and as more projects are completed, divergence between smart cities increases. Interoperability between smart cities, however, is a key goal of many smart city initiatives. This thesis therefore works towards counteracting the problem of lacking architectural interoperability between smart city platforms. In specific, this means counteracting the problem of a vendor lock-in, as a lack of interoperability could force a smart city platform to either abide by a vendor's wishes or to see part of the platform's functionality collapse.

Literature on generic platform ecosystems most prominently exists in the form of the work of Tiwana, A. (2013). Literature on vendor lock-in is widespread, but predominantly focuses itself on cloud-based systems. In order to explore the problem of vendor lock-in in the context of smart city platforms, these two fields of literature have been combined to formulate a conceptual model. Through a multiple-case study involving five smart city platforms, this proposed conceptual model is tested and refined. Based on the findings from case studies, the following conclusions are drawn:

Firstly, the choice of architectural framework has an impact on the relationship between platform interoperability and application openness; following the FIWARE framework leads to a greater application openness. It is hypothesised that following the ESPRESSO framework leads to a better platform governance. This aligns with the suggestion of cooperation between the two, using FIWARE for a narrower, more technical specification, and ESPRESSO for a broader, more strategic overview.

Secondly, a higher level of platform interoperability leads to a higher level of application openness, and a higher level of application openness concerning data standard openness leads to a lower level of predicted vendor lock-in. This validates ESPRESSO's approach towards encouraging interoperability, and contradicts literature that suggests API openness is the most important factor. This might point to differences between generic platforms and smart city platforms.

Thirdly, a higher level of application openness concerning documentation transparency leads to a lower level of predicted vendor lock-in. However, this is a broad set of factors related to policy and documentation, and it is proposed to divide these in two. One, the documenting of e.g. requirements and extensibilities of applications and services. Two, the documenting of exit strategies pertaining to vendors, e.g. whether data be maintained in usable format upon switching. The latter would also account for the awareness a smart city has regarding vendor lock-in, and the amount of coordination a smart city does with others, which have been found to be important factors.

Besides these propositions, a variety of unanticipated conclusions are drawn.
For instance, the maturity of a smart city platform is important to take into account. It is hypothesised that less mature platforms will for example have a lower architecture openness.
Similarly, platform governance is important to take into account. It is hypothesised that both a top-down development approach and the ESPRESSO architectural framework positively moderate a hypothetical relationship between platform governance and application openness.

Academically, these findings contribute to two architectural frameworks and two fields of literature, supporting or rejecting existing theory and bringing forth new propositions to be validated. Managerially, these findings allow smart city platform owners to more concretely steer their activities, gaining a deeper insight in smart city development approaches, architectural frameworks, and factors that affect interoperability and vendor lock-in. In general, closer cooperation is advised.

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1. Introduction

In this thesis, the concept of smart cities will be explored within the context of the EU Ruggedised project. In this chapter, the subject will be introduced, leading to the formulation of a research question and its academical and managerial relevance. Then, relevant themes from this subject will be discussed in the literature review. Based upon this literature study, a conceptual model will be established, after which the research methodology will be defined. A variety of cases will be selected and analysed afterwards, leading to the conclusion of this thesis.

1.1 Motivation

More and more of the world's population lives in increasingly larger cities, a trend that is predicted to continue for at least the coming decades. The world's population is also predicted to increase for the coming decades, compounding this phenomenon.

In 2016, approximately 54.5% of the world's population lived in cities. By 2030, it is estimated that 60% of the world's population will be living in cities (United Nations, 2016). By 2050, 64% to 66% of the developing world's population and 86% of the developed world's population will be living in cities (The Economist, 2012).
Besides the increasing rate of urbanisation, the size of cities will also increase. In 2016, there were 512 cities with one million inhabitants and 31 megacities (cities with ten million or more inhabitants). In 2030, it is predicted that there will be 662 cities with one million inhabitants and 41 megacities (United Nations, 2016).
Finally, the world's population is predicted to increase from 7.6 billion people in 2017 to 8.6 billion by 2030 and to 9.8 billion by 2050 (United Nations, 2017).

Alongside this trend of urbanisation, other global trends exist, such as the decentralisation of government, climate change, changing demographics (e.g. migration and aging), and increasing social inequality (UN Habitat, 2016). Taken together, these trends give rise to a wide variety of urban problems. For example, in 2014, 56% of cities with at least 300.000 inhabitants – 1.4 billion people in total – faced a high risk of exposure to a natural disaster, a number that has increased since then with the increase of urbanisation and climate change (United Nations, 2016). Other examples consist of difficulty in waste management, scarcity of resources, air pollution, traffic congestion, and deteriorating infrastructure (Nam and Pardo, 2011). To counteract these problems, the concept of a smart city has arisen.

Smart cities know a multitude of definitions. For instance: "Smart cities are cities built on 'smart' and 'intelligent' solutions and technology that will lead to the adoption of at least 5 of the 8 following smart parameters – smart energy, smart building, smart mobility, smart healthcare, smart infrastructure, smart technology, smart governance and smart education, smart citizen" (Frost and Sullivan, 2013). These parameters indicate the envisioned opportunities for smart cities.
Similar parameters are found in conceptual models of smart cities, for example: Smart infrastructure, smart transportation, smart environment, smart services, smart governance, smart people, smart living, and smart economy (Anthopoulos, 2017).
International organisations, such as the International Standards Organization (ISO) and the International Telecommunications Union's Focus Group on Smart Sustainable Cities (ITU FG-SSC), have sought to define Key Performance Indicators (KPIs) for smart cities (Deloitte, 2015). Here as well, similar parameters appear.
Or, as the NEN SAG-SC Urban Platform states (freely translated): Smart city projects must answer society's most pressing needs, such as urban sprawl, air quality, aging population, and mobility, taking principles of sustainability, quality of life, resilience, and inclusiveness of all people into account (Verhoeff, n.d.).

For the purpose of this chapter, it suffices to give an idea of what a smart city is by the above mentioned parameters, describing possible roles and functions of a smart city by opportunities to exploit and threats to overcome. For a broader overview, see Appendix I: 'Supplemental Literature'

By 2025, it is predicted that 26 smart cities will exist (Frost and Sullivan, 2013), yet it is similarly predicted that by 2020 the smart city market will increase in value to be anywhere from $0.4 trillion to $1.5 trillion (Deloitte, 2015). This indicates a gigantic market that will only grow, as more and more cities will become smart cities.

Lacking a clear definition of a smart city, and further lacking clear roles for smart cities, possible threats emerge. For instance, there are no criteria for what can be labelled a smart solution (Deloitte, 2015), nor are there common criteria that smart solutions must adhere to. Similarly, there are no clear standards for the architectural designs underlying these smart solutions. Some of these architectures and smart solutions are not interoperable, nor are they converging towards one interoperable standard (Burns, 2017). In fact, many smart city platforms and applications rely on systems that are not interoperable, portable (to other smart city platforms), extensible, or cost effective (Greer and Maestosi, 2017). This can detract from the success of smart cities, as different platforms or services might prove incapable of interacting in an efficient manner (or at all) with others.

One possible issue in specific is the phenomenon of vendor lock-in (Opara-Martins et al., 2016); making a customer dependent on a single vendor's applications and / or services, as the customer is incapable of using another vendor without incurring severe switching costs. This can, for example, force a smart city platform to either abide by the vendor's wishes or to see part of the platform's functionality collapse.

This issue is not easily solved. Fundamentally, the difficulty is theorised to lie in the way APIs access the platform, which has not been standardised, and thus might result in a vendor lock-in. For example, two vendors might have contradicting ways of accessing the platform, forcing the platform owner to choose between the services of one vendor over the other (Opara-Martins et al., 2016).
As of yet, this issue has been primarily approached from a technical perspective, instead of a business perspective (Opara-Martins et al., 2016). However, this issue is of a social and organisational nature, concerning multiple diverse stakeholders with competing values yet high levels of interdependence in the politically complex environment of a city (Nam and Pardo, 2011). To tackle this, a system-wide (i.e. on the level of a platform, not on that of a given application) approach is needed, requiring standards, portability, and interoperability to be supported by platform providers (Opara-Martins et al., 2016).

This so that smart cities may eventually coordinate and cooperate worldwide, without being locked in to certain applications or approaches. This would increase the amount and quality of the services and applications possible on any smart city platform, leading to higher living standards.

1.2 Problem Statement

The eventual objective of this thesis is to counteract the problem of lacking architectural interoperability between smart city platforms. In specific, this means counteracting the problem of vendor lock-in, as detailed in paragraph 1.1 'Motivation'. In order to do so, a conceptual model bridging two fields of literature – that of platform ecosystems and of vendor lock-in – will be proposed and tested. Therefore, the immediate research goal of this thesis is explanatory in nature; to explain the phenomenon of vendor lock-in through a proposed conceptual model concerning interoperability and vendor lock-in.

A variety of efforts are already being conducted to encourage architectural interoperability and to prevent vendor lock-in:

1. ESPRESSO is developing a 'Conceptual Smart City Information Framework'. It agrees that a system-wide approach to standardisation is necessary, and recognises both the technical perspective (technological complexity) and the business perspective (the complexity of the various sectorial services) (ESPRESSO, 2017). This project will identify open standards and a baseline for interoperability, to be brought together in a framework, based on a requirements-engineering campaign with cities (De Lathouwer, 2016). In specific, ESPRESSO emphasises "avoiding lock-in to proprietary solutions". The smart city of Rotterdam (amongst others) uses the ESPRESSO approach.
   The WS2 Reference Architecture (a reference framework for a standard architecture) has been developed by certain international organisations, such as the USA-based National Institute of Standards and Technology (hereafter 'NIST'). They are cooperating globally, bringing together a multitude of organisations, and thereby taking the diverse and politically complex business perspective into account. ESPRESSO has aligned with this initiative, and has incorporated the WS2 Reference Architecture, as both seek mutual consensus and consistency (Cox et al., 2016: 15).
2. The FIWARE Architecture for Smart Cities is one of the technologies analysed according to the Cyber-Physical Systems (CPS) Framework. FIWARE is an "open sustainable ecosystem, built around public, royalty-free and implementation-driven software standards." (FIWARE, n.d.). The smart city of Utrecht (amongst others) uses the FIWARE approach.

With a multiple-case study design based around these two approaches, this thesis will seek to validate a proposed conceptual model for assessing the likelihood of vendor lock-in and to identify the degree to which certain smart city cases are vulnerable to vendor lock-in.
In doing so, this thesis will answer the following research question:

"How do smart city platform architectural factors contribute to vendor lock-in of smart city platform owners?"

In order to answer this, a set of sub-questions has been developed:

1) What are relevant types of smart city platform architectures?
2) What are relevant types of vendors in a smart city context?
3) How can vendor lock-in be assessed?
4) What are relevant smart city platform architectural factors?
5) How do the smart city platform architectural factors influence vendor lock-in?

1.3 Relevance

This thesis's academical relevance is found in contributing to smart city architecture frameworks, and this thesis's results can be used as a stepping stone to a deeper or more comprehensive smart city architectural model. In general, this thesis's results contribute to literature on (standardisation of) multi-sided platforms (e.g. Tiwana, 2014).

In specific, there are multiple models for and implementations of smart city architectures that will be analysed. One example of a step towards standardising these architectures, is the NIST's definition of 'Pivotal Points of Interoperability' (PPIs): "Consensus standardised interfaces that deal with composition of CPS without constraining innovation." (Burns, 2017). These are the most important factors that open APIs need to account for in order for interoperability to exist.
Interoperability is the opposite of what a vendor lock-in would entail, and architectures adhering to the principles of PPIs would as such not be vulnerable to vendor lock-in (Burns, 2017). Therefore,

'vendor lock-in' is the operalisation of 'non-interoperability', which is the exact opposite of 'interoperability'.
Convergence is taking place between the various models. ESPRESSO is working on the comparable 'Minimal Interoperability Mechanisms' (MIMs) (Appendix I.II: 'Architectural Frameworks'), and FIWARE has been analysed through the PPIs of the WS2 Reference Architecture (Appendix I.III: 'Cyber-Physical Systems Framework'). This all to encourage interoperability in the context of smart city architectures.
However, other factors besides open APIs might influence interoperability. It is academically relevant to research this assumption. By investigating multiple cases of multi-sided platform architectures, it can be assessed which factors have which effect on vendor lock-in (the operalisation of non-interoperability).

This thesis's business relevance is found in the practical implication of assessing the differences between the aforementioned architectural approaches with regards to vendor lock-in. It holds practical implications for platform providers, developers of applications, service providers, and customers (or, platform users) alike. By offering a tested framework of factors contributing with differing degrees to vendor lock-in, insight can be gained by all of these parties in how to prevent a vendor lock-in from occurring.

More specifically, this thesis's business relevance is found in the EU Ruggedised initiative:
"RUGGEDISED is a smart city project funded under the European Union's Horizon 2020 research and innovation programme. It brings together three lighthouse cities: Rotterdam, Glasgow and Umeå and three follower cities: Brno, Gdansk and Parma to test, implement and accelerate the smart city model across Europe. Working in partnership with businesses and research centres these six cities will demonstrate how to combine ICT, e-mobility and energy solutions to design smart, resilient cities for all." (EU, n.d.)
This thesis is grounded in the context of the smart city of Rotterdam as one of the aforementioned lighthouse cities. Furthermore, the Dutch telecommunications company Koninklijke KPN N.V. (KPN) and the smart city of Utrecht (a lighthouse city of IRIS, an initiative part of HORIZON 2020 and similar to EU Ruggedised) cooperate together with Rotterdam. The knowledge obtained by this thesis may further be used for smart city platforms beyond Rotterdam's, such as those part of the various EU-wide smart city initiatives, especially because at the moment it is often unknown what each city is doing at all.

Finally, addressing the concerns raised in paragraph 1.1 'Motivation', optimally managing the transition from traditional cities to smart cities is of relevance to governments, businesses, and individuals worldwide. Governments need to guide their country into the future, especially taking society's most pressing needs into account, and businesses can derive a wealth of new opportunities from smart city programs. As the project manager of Rotterdam City Development and member of an advice board for standardising smart cities says, the term 'smart city' has expanded to include the objective of making the city future-proof (Vieveen, 2016).

2. Literature Review

Here the literature review, in order to expand upon the terms and questions raised as part of the research question.

2.1 Platform

A variety of platform architectures exist, but this thesis concerns itself with open smart city platforms. This paragraph serves to identify which platform architectures correspond with open smart city platforms, which will partly answer sub-question one: "What are relevant types of smart city platform architectures?".

Baldwin and Woodard (2008) define a platform architecture as: "modularizations of complex systems in which certain components (the platform itself) remain stable, while others (the complements) are encouraged to vary in cross-section or over time."
Baldwin and Woodard (2008) go on to state that the modular interfaces that mediate between the platform and its complements – that govern the interaction of components – are among the most stable elements in a platform architecture. Therefore, the interface specifications are part of a platform architecture. This becomes evident when considering characteristics of open smart city platforms.

The EIP-SCC Open Urban Platforms (Heuser et al., 2017) lists four characteristics of open smart city platforms:

- They integrate data flows within and across city systems through a logical architecture.
- They exploit modern technologies; e.g. sensors, cloud services, mobile devices, analytics, or social media.
- They enable cities to shift from fragmented operations to predictive effective operations.
- They offer tangible and measurable control over local factors, e.g. increasing energy efficiency, reducing traffic congestion, or reducing emission.

This is not dissimilar to certain more generic platforms, such as Uber. As Ramamurthy (2015) notes, location sensors in mobile devices send information to Uber's cloud service, and Uber uses (near real-time) analytics to determine the most suitable driver for a passenger. Passengers and drivers have the opportunity to rate each other or to communicate with each other (reminiscent of social media). Uber uses all this data (and more, such as geographic, weather, or seasonal data) to predict, for example, the time of arrival (both of the driver to the passenger and of the passenger to his or her destination) and areas of high demand (with many passengers). This results in a coordinated and predictive system of drivers and passengers, that allows for better split-second decision making than most human dispatchers could.

Or, as Ramamurthy (2015) describes IoT platforms:

- Requests and data from sensors and human observers are transmitted to a cloud-based system.
- A fast decision-making subsystem processes the incoming requests and data.
- This system uses context, provided by a system that analyses multiple sources of data, to trigger an action.
- Actions can also automatically be triggered through analytics (e.g. Business Activity Monitoring, Complex Event Processing).

This, in turn, is not dissimilar to smart cities. Ramamurthy (2015) notes that a key capability of IoT platforms is to put requests, data, and observations in a context, allowing them to respond intelligently and (where desired) autonomously. This context-driven intelligence aligns well with proposed smart city functions, such as automatically turning on lights or notifying structural weaknesses in buildings. Other literature (e.g. Jin, 2014) agrees with the characterisation of a smart city as an IoT platform.

Therefore, any relevant type of smart city architecture must be analysed as part of a multi-sided platform, comparable to IoT platforms through the bullet points above.

2.2 Openness

This paragraph serves to operationalise the 'open' part of 'open smart city platforms'. The previous paragraph relates to the functional comparison of smart city platforms with more generic (multi-sided) IoT platforms. However, smart city platforms are generally intended to be open platforms, which for example Uber is not. Clarifying 'openness' will further answer sub-question one: "What are relevant types of smart city platform architectures?".

Platforms are 'open' when there are either no restrictions, or fair and reasonable restrictions, on participating in the platform's development, commercialisation, or use. Fair and reasonable restrictions include conforming to technical standards, or paying license fees, so long as these apply to all platform participants (Eisenmann et al., 2009).

Eisenmann et al. (2009) identify four categories of platform participants: Demand-side platform users (or 'end users'), supply-side platform users (who develop applications for the platform), platform providers (who provide the hardware that the platform runs on), and platform sponsors (who hold property rights, develop the platform's technology, and determine who may participate on the platform). For each of these categories, the platform may be open or closed.
Crucially, the openness of these categories differs between generic IoT-platforms and smart city platforms in specific. For example, a smart city would generally be open (fair, non-discriminatory, equal access) to all demand-side platform users (citizens), while this would not often be the case for generic IoT-platforms. The categories themselves also differ, because of the complex political nature of smart cities (i.e. municipalities). Therefore, generic IoT-platforms are not sufficiently comparable to smart cities for the purpose of this thesis.

Among various advantages of opening platforms (e.g. stimulating the production and adoption of differentiated applications and services to better meet the customers' needs), Eisenmann et al. (2009) mention: "reducing users' concerns about lock-in". In other words; a higher level of interoperability leads to a lower chance of vendor lock-in.

Eisenmann et al. (2009) indicate that downsides of opening platforms are commercial in nature (e.g. reducing switching costs and increasing competition with rival platform providers). This is the perspective of a platform owner that seeks to earn profit with his or her platform. However, the EU Ruggedised initiative takes the perspective of a citizen, citing as one of its goals: "Improving the quality of life of citizens, by offering them a clean, safe, attractive, inclusive and affordable living environment." These downsides of opening platforms can thus be ignored, as the EU Ruggedised initiative does. Extending smart city best practices from three 'lighthouse cities' to other cities – 'rival' platform providers – is inherently part of this initiative, as is a high degree of openness (EU, n.d.).

In this case, 'openness' is the same as 'interoperability', which is intuitively similar to 'standardisation'. For example, the consortium behind the WS2 Reference Architecture formulated PPIs to achieve a balance between standardising everything and standardising nothing; the former

would mean freezing innovation, allowing for no uniquities, while the latter would mean no interoperability and no integration (Burns, 2017).
'Openness' is a recurring theme in the WS2 Reference Architecture; the architecture is meant for 'open urban platforms' and 'open' is mentioned seventeen times in the introduction alone. Further, 'openness & interoperability' is one of the technology factors positively influencing smart city solution adoption and upscaling (Erasmus Centre for Future Energy Business, 2017).
One of the reasonable restrictions that do not impede a platform's openness, per Eisenmann et al. (2009), is 'conforming to technical standards'. This harkens back to Opara-Martins et al. (2016), who state that not conforming to the same technical standards – APIs using different ways to access a platform – might result in a vendor lock-in. Similarly, Cox et al. (2016) speak of a "vendor agnostic approach that will result in an enhanced interoperable, standards-based architecture and implementation".
To some extent, 'openness' and 'standardisation' – or 'interoperability' – can thus be conflated.

This thesis operationalises 'interoperability' by looking at the very opposite of it; the phenomenon of vendor lock-in (thus; a higher level of interoperability leads to a lower chance of vendor lock-in). Eisenmann et al. (2009) cite vendor lock-in as being a phenomenon dependent on the openness of a platform. For the eventual case selection, it should be kept in mind that not all IoT platforms are open platforms.

Thus, the relevant types of smart city platform architectures consist of multi-sided smart city platforms that are (theoretically, or intended to be) open. Should a vendor lock-in have occurred, the interoperability will be decreased (and thus, in practice, the platform's openness as well).
This also begins to formulate an answer to sub-question four; the degree of interoperability is a relevant smart city platform architectural factor that affects vendor lock-in. The proposition that 'a higher level of interoperability leads to a lower chance of vendor lock-in' could now be made, but should be refined by diving deeper into the literature to develop the eventual conceptual model.

2.3 Platform Ecosystem

Having analysed 'openness' in the preceding paragraph, it is noted that the degree of openness is a choice that can be made by the platform owner. This would have an influence on both the platform's architecture as well as on the platform's applications, and would indirectly influence the likelihood of vendor lock-in occurring. This can be seen as a platform architecture's underlying vision, or how the platform's ecosystem is leveraged.

Platform architecture is defined by Tiwana, A. (2014) as follows: "A conceptual blueprint that describes how the ecosystem is partitioned into a relatively stable platform and a complementary set of apps that are encouraged to vary, and the design rules binding on both". Therefore, Tiwana, A. (2014) considers there to be a 'platform (architecture)' and 'apps', with 'platform architecture' affecting 'apps', and with 'ecosystem' affecting the relationship between them.
Tiwana, A. (2014: 6)'s 'elements of a platform ecosystem' also includes 'shared infrastructure'. This is because the platform ecosystem can be divided into its upstream and downstream parts of a value chain. The upstream part includes for example component suppliers, manufacturing partners, and infrastructure providers, while the downstream part includes for example app developers and service providers. The attractiveness and fate of the platform primarily depend on the downstream part (Tiwana, 2014: 7). It can be inferred that the shared infrastructure – the upstream part – would only play a role for vendor lock-in if, for example, a provider's network topology would restrict access to a certain platform. These kind of scenarios seem too extreme to include in a conceptual model; the goal is to provide a functionally useable model. However, if relevant, they will be taken into account during the case analyses to tell the full story.

To further define 'ecosystem' for the context of smart cities, other literature is perused.
Mulligan and Olsson (2013) identify a top-down approach and a bottom-up approach for developing the platform (architecture) and the applications on top of it. A top-down approach "arises from a well-defined strategic vision of the smart city […] to reach shared goals stated from the beginning" (Dameri, 2013). A bottom-up approach, on the other hand, start with the application of technology to urban problems, by universities, research institutions, and hi-tech companies, who gradually shape the smart city. These approaches would be part of the 'ecosystem' of Tiwana, A. (2014).

Mulligan and Olsson (2013) identify two top-down architectural approaches; that of the telecommunications industry and that of the ICT industry. The approach of the telecommunications industry accounts slightly more for the social context, as this approach includes the citizens' identities. For example, if a citizen of the Netherlands makes a phone call in Greece, this information will be forwarded from Greece to the Dutch telecom provider of this citizen. However, these are both top-down approaches.
The two top-down approaches identified by Mulligan and Olsson (2013) fail to account for the uniquities of urban environments; in specific, that humans form the basis of any city. Mulligan and Olsson (2013) argue that the basis of any smart city is "the interaction between the human, the digital technology, and the city", and similarly, Dameri (2013) notes that "the most important subjects in the smart city definition should be the citizens". A smart city architecture therefore needs to include the role end users – citizens – play in capturing, delivering, and generating data. Not only the technical context – as the architectural approach of the telecommunications industry does – but also the social context; to make the data meaningful, privacy concerns will have to be addressed so that citizens feel willing and safe to share their data (Mulligan and Olsson, 2013).

A third, more bottom-up approach, does in part account for this social context; citizens participate on the smart city platform, being directly involved with the development of applications (Mulligan and Olsson, 2013). However, this bottom-up approach consists of many independent initiatives without an overarching vision. To meaningfully address privacy concerns, a comprehensive vision of the smart city and its governance is needed, and this is often lacking for a bottom-up approach (Dameri, 2013).
Further, because of its origin in the application of technology to urban problems, the bottom-up approach often operates on existing infrastructure and within the technical boundaries of the APIs used by the most important companies. This results in difficulties with scaling up and achieving longevity (Mulligan and Olsson, 2013). In essence, this kind of approach seems to increase the chance of a vendor lock-in occurrence. This is problematic, as Cox et al. (2016) note: "In practice, most cities will take a melded approach, combining aspects of the top down and bottom up approaches.", and Dameri (2013) states that "smart city is not a top-down phenomenon, but a bottom-up one".

In conclusion, Mulligan and Olsson (2013) note comparatively minor differences between the two top-down architectural approaches. However, they note larger differences between a given top-down approach and a bottom-up approach.
Therefore, 'platform ecosystem' consists of the current smart city development approach, which can be:

- A demand-driven bottom-up approach that develops individual use cases.
- A top-down approach that develops an overarching platform.

Mulligan and Olsson (2013) are particularly concerned with the social context necessary for smart city architectures; how to include citizens when creating smart cities? Not only in the development

approach, but also in the outcome of the development process. Speaking of business models, they note: “A key question for the architecture of any smart city solution must therefore be how to effectively link the human into the solution architectures for smart cities, while ensuring appropriate scale to keep costs low enough to create a smart city market.”. From personal communications (Appendix II: ‘Interviews’, IV), this is envisioned as either a data market, or as a digital community. The latter would include a data market, but would go beyond that in allowing for the creation and offering of applications and services as well.
Therefore, ‘platform ecosystem’ also consists of the ideal outcome of the smart city development process, which can be:

- A data market where everyone can pull data from using prescribed services and applications.
- A digital community where everyone can use and develop services and applications.

Further, per 1.2 ‘Problem Statement’, the WS2 Reference Architecture and the ESPRESSO approach (an ICT-originated architecture) and the FIWARE approach (a telecommunications-originated architecture, when viewed in relation to TMForum) are sensible choices for investigation. The related architectures are part of a larger approach, and as such do not necessarily need to be applied in a top-down manner, contrary to the identifications of Mulligan and Olsson (2013).
Therefore, ‘platform ecosystem’ also consists of the architectural framework underlying the smart city, which can be:

- An integrated and controlled system in which modules are documented and developed by a private party, guaranteeing the quality of these modules when working together (e.g. FIWARE’s ‘grand design’).
- A set of interface-related standards that are already widely in use, allowing other parties to develop their own products while accounting for these standards (e.g. ESPRESSO’s MIMs and PPIs).

The first proposition can now be made:

Proposition 1: Platform Ecosystem has an impact on platform and applications.

Specifically:

Proposition 1a: A ‘top-down’ development approach positively moderates the relationship between Platform Interoperability and Application Openness.[1]
Proposition 1b: A ‘digital community’ ideal outcome positively moderates the relationship between Platform Interoperability and Application Openness.[1]
Proposition 1c: The choice of architectural framework has an impact on the relationship between Platform Interoperability and Application Openness.[1]

This further answers sub-question one: “What are relevant types of smart city platform architectures?”.

2.4 Vendor Lock-In

This paragraph will answer the second sub-question: “What are relevant types of vendors in a smart city context?”, as well as the third sub-question: “How can vendor lock-in be assessed?”.

[1] ‘Application Openness’ is measured through ‘Data Standard Openness’, ‘API Openness’, and ‘Architecture Openness’, and will be analysed as such during the case studies.

Although largely treated as a negative phenomenon, vendor lock-in is not an inherently negative phenomenon, nor is it necessarily desirable from a vendor's point of view; a lock-in situation is only sustainable in the short-term (Appendix II: 'Interviews', I and VI).
A vendor lock-in is also not a binary status that either occurs or does not occur. There are various degrees, and some kind of vendor lock-in might be impossible to avoid.

Per the research question, this thesis will investigate vendor lock-in from the perspective of the smart city platform owner.

The EU Ruggedised perspective considers a variety of stakeholders (EU Ruggedised, 2018):

- Data user, who wants certain services or applications;
- App developer, who develops these services or applications;
- Data provider, who provides data to the platform, possibly through an intermediary data broker;
- Urban data platform operator / data trustee, who fulfils the platform (and data) ownership role.

Literature (e.g. Silva, 2013; Hill and Humphrey, 2010) mainly focuses on vendor lock-in in the context of the cloud. Generally, three parties are considered, that map very well to the above perspective:

- The customer, who wants certain services or applications stored in the cloud ('data user');
- The vendor, who develops these services or applications ('app developer' and 'data provider');
- The platform provider, being the cloud itself.

The roles are not mutually exclusive. Sometimes, the data user (customer) takes on the role of the app developer (vendor), developing the required services or applications as well as using them. Similarly, a data provider can both be a data user or app developer as well.
The role of 'platform provider' could be the 'urban data platform operator / data trustee', but in the context of smart cities, there often is a difference between 'platform provider' and 'platform operator'. The former is a party that provides the technical platform, such as KPN or Civity, but that does not fulfil a governance function. The latter is for example the municipality of Rotterdam or the municipality of Utrecht, and it is this last role that this thesis concerns itself with as 'smart city platform owner'.

A vendor lock-in can happen in multiple scenarios. For this thesis, only those kinds of vendor lock-in that take place in a multi-sided platform environment, similar to that of smart cities, will be considered. For example:

- Cloud services can prevent a user from transferring data from one cloud service to another. A similar lock-in might occur on mobile devices, and on platforms in general, forcing the smart city platform owner to stay with a certain cloud service.
- A user can be locked into the broader ecosystem of a vendor (e.g. Google Assistant only works with other Google products, such as Gmail or Google Calendar). This becomes a true vendor lock-in if, much like with certain cloud services, there is no functionality to conveniently export one's data to a different application, forcing the smart city platform owner to stay within this ecosystem.

In the context of smart cities, the platform provider wants their platform to be able to make use of a variety of applications, services, and data, regardless of whether they were developed for a specific platform or by a specific vendor. The platform provider further wants their platform to be interoperable with other platforms, so that smart cities can communicate and cooperate worldwide.

In order to answer the research question, vendor lock-in must be measured at two periods of time, so as to measure how smart city architectural factors have affected vendor lock-in. Because smart city initiatives are ongoing developments (Wagenaar, 2016; Andriessen, 2017), the current and the predicted (after the realisation of the smart city platform) vendor lock-in will be measured.
Intuitively, the degree of vendor lock-in can be measured by measuring the switching costs of switching from one vendor (platform, application) to another. These switching costs are measured in both money and time (e.g. Varian, n.d.; Li, 2017). A contract clause might theoretically allow for 'instant' switching at a hefty financial cost, which could prevent a user from switching in practice; a switching cost of money. Similarly, a program might in practice make use of closed standards or interfaces, preventing a user from switching to another program without losing their work; a switching cost of time.
Literature expands upon these two basic switching costs depending on which subject they want to explore. Broadly, three categories can be made herein; switching costs as a result from the impossibility of data interchange, from the chosen API strategy, and from architectural factors (e.g. the portability of an application on a platform).
A fourth category, the accessibility of (source) code (e.g. Silva, 2013; Petcu et al., 2013), is deemed to fall under architectural factors, as the accessibility of source code relates to the portability of the application.

These factors are expanded upon below:

- Data standard openness
  - The data stored on the platform (or, generated by applications on the platform) should be freely accessible to users (note that this does not preclude commercial use of data). This includes making use of common database standards (i.e. applications make use of mutually interoperable data formats and data stores), using open formats for data interchange, and allowing users to mutate and export their data (e.g. Cloud Standards Customer Council, 2017; Ardagna et al., 2012).
- API openness
  - Applications on the platform should have the (theoretical) ability to have programmatic access to each other, using open standards, so that one application can communicate and interact with another when desired. (e.g. Toosi et al., 2014; Martino et al., 2014).
- Architecture openness
  - Applications and dependencies should be able to be ported easily across platforms. This means that there are no proprietary runtime programs, languages, frameworks, databases, libraries, or other third party services necessary for the application to function. In other words; the application architecture should make use of a common set of standards (e.g. Martino et al., 2015; Binz et al., 2012).

Finally, there are factors related to policy and documentation; intuitively, other factors exist that affect vendor lock-in. For example, specifying an exit strategy during contract specification, defining clear requirements including the option for extensibility, or being aware of commonalities and dependencies, all decrease the chance for a vendor lock-in to happen (e.g. Opara-Martins, 2016; Tiwana, 2014; Seroter, 2016). These factors depend in part on platform-governance alignment, but are too many to list in full. These will be taken into account during the case analyses to the best extent possible.

These are all factors on the level of an application, not of a platform. With these, a second proposition can be made:

Proposition 2: A higher level of Application Openness leads to a lower level of Predicted Vendor Lock-In.[2]

2.5 Interoperability

Having broached sub-question four in paragraph 2.2 'Openness', this paragraph will further investigate sub-question four: "What are relevant smart city platform architectural factors?"

Literature seems to agree that the fundamental cause of vendor lock-in is the lack of interoperability of APIs, resulting from multiple largely independent initiatives with a lack of an overarching vision or governance (e.g. Opara-Martins et al. (2016) in paragraph 1.2 'Problem Statement', Eisenmann et al. (2009) in paragraph 2.1 'Platform', Dameri (2013) in paragraph 2.3 'Platform Ecosystem', and Mulligan and Olsson (2013) in Appendix I.I: 'City').
However, outside of academical literature, personal communications (Appendix II: 'Interviews', IV, V, and VI) and documents related to this thesis's subjects reveal that other causes of vendor lock-in exist as well. Most hypothesise that 'data standard openness' may be more relevant (further expanded upon in Appendix I.II: 'Architectural Frameworks').

Cox et al. (2016) mention: "ESPRESSO's approach emphasizes cost reduction and will foster an open market for many actors, avoiding lock-in to proprietary solutions".
This approach refers to their definition of an open standard, which:

- Is non-proprietary and revisable by any party in an open process.
- Is freely distributable, not restricting any party from distributing it as part of a software distribution.
- Has open (interface) specification access.
- Does not discriminate against any individual or group.
- Is technology neutral and therefore does not require a specific type of underlying platform, database, or interface.

ESPRESSO aligns as much as possible with the output of WS2 (the work stream behind the WS2 Reference Architecture), and the two parties have cooperated in the establishment of the above source. It is further mentioned that both parties will continue to support one another, pursue consensus, and maximise consistency (Cox et al., 2016: 15). A connection can thus be established between the openness of standards and the lack of vendor lock-in. In specific, the above factors can be used to measure the openness of standards; the interoperability.

Further, parallels can be drawn with other literature. Toosi, A.N. et al. (2014) note that interoperability can be obtained through standardising interfaces, for example, while Tiwana, A. (2014) notes that compliance with a platform's interface standards and APIs results in interoperability. This relates to the 'API openness' factor from paragraph 2.4 'Vendor Lock-In'.

Often, 'interoperability' is mentioned together with 'portability', a relation that can also be inferred from the above definition of an open standard. Portability can be viewed as the external interoperability; how interoperable is an application with a different platform (or, how transferable

[2] 'Application Openness' is measured through 'Data Standard Openness', 'API Openness', 'Architecture Openness', and 'Documentation Transparency', and will be analysed as such during the case studies.

are the data and services that an application provides)? This is a consequence of the chosen platform and further depends on certain application-specific factors (e.g. whether another application or a framework was used to develop this application). It aligns with the 'architecture openness' factor from paragraph 2.4 'Vendor Lock-In'.

Summarising, a third proposition can be made:

Proposition 3: A higher level of Platform Interoperability leads to a higher level of Application Openness.[3]

This is not an exhaustive list of factors relating to interoperability for smart cities. However, other factors would be found in for example the governance mechanism, and not in the platform architecture. This fits better with resilience, discussed in paragraph 2.6 'Resilience'.
An example could be that multiple smart cities agree on common interfaces and standards, while each city individually procures systems, enabling the emergence a multi-vendor market.
Another example could be the role of a gatekeeper, which integrates all data in one silo as opposed to closed, vertically integrated systems (that are not interoperable with other cities).
Much like policy- and documentation-related factors regarding vendor lock-in, factors like these are not specified to a detailed level for this thesis's purpose, as there might be innumerable such factors. This would preclude the development of a generally applicable conceptual model. However, 'platform-governance alignment' would account for these factors, as part of 'resilience', and the full story will be taken into account during the case discussion.

2.6 Resilience

Having broached sub-question four in paragraph 2.2 'Openness', this paragraph will further investigate sub-question four: "What are relevant smart city platform architectural factors?".
To this end, literature on the Cyber-Physical Systems Framework (e.g. Cyber Physical Systems Public Working Group, 2017) has been cross-referenced with that on platform ecosystems (e.g. Tiwana, A., 2014), amongst other sources.

Within the context of the Cyber-Physical Framework (Appendix I.III: 'Cyber-Physical Systems Framework'), 'trustworthiness' is suggested to be the most relevant zone of concern for this thesis's purpose (Appendix II: 'Interviews', III). 'Trustworthiness' is operationalised as follows:

- Privacy; concerns related to the ability of the CPS to prevent entities (people, machines) from gaining access to data stored in, created by, or transiting a CPS or its components, such that individuals or groups cannot seclude themselves or information about themselves from others.
- Reliability; concerns related to the ability of the CPS to deliver stable and predictable performance in expected conditions.
- Resilience; concerns related to the ability of the CPS to withstand instability and unexpected conditions, and gracefully return to predictable, but possibly degraded, performance.
- Safety; concerns related to the ability of the CPS to ensure the absence of catastrophic consequences on the life, health, property, or data of CPS stakeholders and the physical environment.

[3] 'Application Openness' is measured through 'Data Standard Openness', 'API Openness', and 'Architecture Openness', and will be analysed as such during the case studies. A higher level of 'Platform Interoperability' is not proposed to lead to a higher level of 'Documentation Transparency'.

- Security; concerns related to the ability of the CPS to ensure that all of its processes, mechanisms, physical and data, and services are afforded internal or external protection from unintended and unauthorized access, change, damage, destruction, or use.

Some of these factors seem particularly relevant for smart cities, especially given the pressing needs mentioned in paragraph 1.1 'Motivation'. Rotterdam, for example, focuses on resilience (Stokman, 2017; Interview VII), and literature on both Cyber-Physical Systems (Cyber Physical Systems Public Working Group, 2017) and on platform ecosystems (Tiwana, 2014) mention 'resilience' as an important factor: "One defective app should not cause the entire ecosystem to malfunction. The key to such resilience is to ensure that apps are weakly coupled with the platform through interfaces that do not change over time. This approach of keeping platform–app dependencies to a minimum also makes the entire ecosystem more stable in its performance." (Tiwana, 2014).
Both sources seem to interpret resilience in a similar manner. According to Tiwana, A. (2014: 212), key drivers of resilience are a platform's architecture (through modularising interfaces and incorporating redundancy in external services) and platform-governance alignment. Tiwana, A. (2014: 165) uses 'recovery time of a platform or app after a failure outside of it' as a proxy measure for measuring resilience.
The Cyber Physical Systems Public Working Group (2017) takes a more technical approach, noting for example fault tolerance and microcontrollers that maintain acceptable performance. This seems to align with the aforementioned proxy measure. Just like with incorporating redundancy, this ensures that the loss of one critical app can be accounted for by the platform.

Tiwana, A. (2014) does extensively consider platforms and apps in the analysation of platform ecosystems, but does not extensively consider data. 'Data' is either mentioned as part of apps (e.g. 'the four pieces of an app's internal functionality' include 'data access logic' and 'data storage') or in contexts such as allowing both 3G and WIFI to be used for data transport. The former is the same context as that of the proposed model, but is not expanded upon any further, while the latter is in the context of external sources, not in the context of applications or databases on the platform that the proposed conceptual model includes. Therefore, 'resilience' does not seem to have an effect on 'data'.

A fourth proposition can be inferred:

Proposition 4: A higher level of Platform Resilience leads to a higher level of Application Openness.[4]

According to Tiwana, A. (2014), resilience, scalability, composability, stickiness, and plasticity, are all architectural metrics that drive platform evolution.
Scalability consists of factors that are related to interoperability, but are already covered by other metrics (e.g. standardising platform interfaces and decoupling apps), and factors that are unique to scalability but do not relate to interoperability (e.g. offering tiered pricing).
Similarly, composability consists largely of modularisation through standardising interfaces and decoupling apps and platform-governance alignment, both of which are already covered.
Stickiness, unlike resilience and scalability, does not concern itself with interoperability. Instead, stickiness is about the use of a platform by users and developers. This does align somewhat with

[4] 'Application Openness' is measured through 'API Openness', 'Architecture Openness', and 'Documentation Transparency', and will be analysed as such during the case studies. A higher level of 'Platform Resilience' is not proposed to lead to a higher level of 'Data Standard Openness'.

vendor lock-in, but Tiwana, A. (2014) refers to a noncoercive end user lock-in based on value, which is not the kind of lock-in this thesis investigates.
Plasticity is a measurement of the level of innovation that is realised on a platform. Amongst other ways, this can be achieved through platform modularisation, which amongst other ways, can be achieved by decoupling apps. This small part of plasticity is already covered.

Crucially, 'resilience' is clearly different from 'interoperability', but both have similarities in their effects on certain other factors. This allows for the combination of literature with a clear link to interoperability, to aggregate a cohesive conceptual model.

3. Conceptual Model

Based on the research question and the subsequent literature review, the conceptual model is formed:

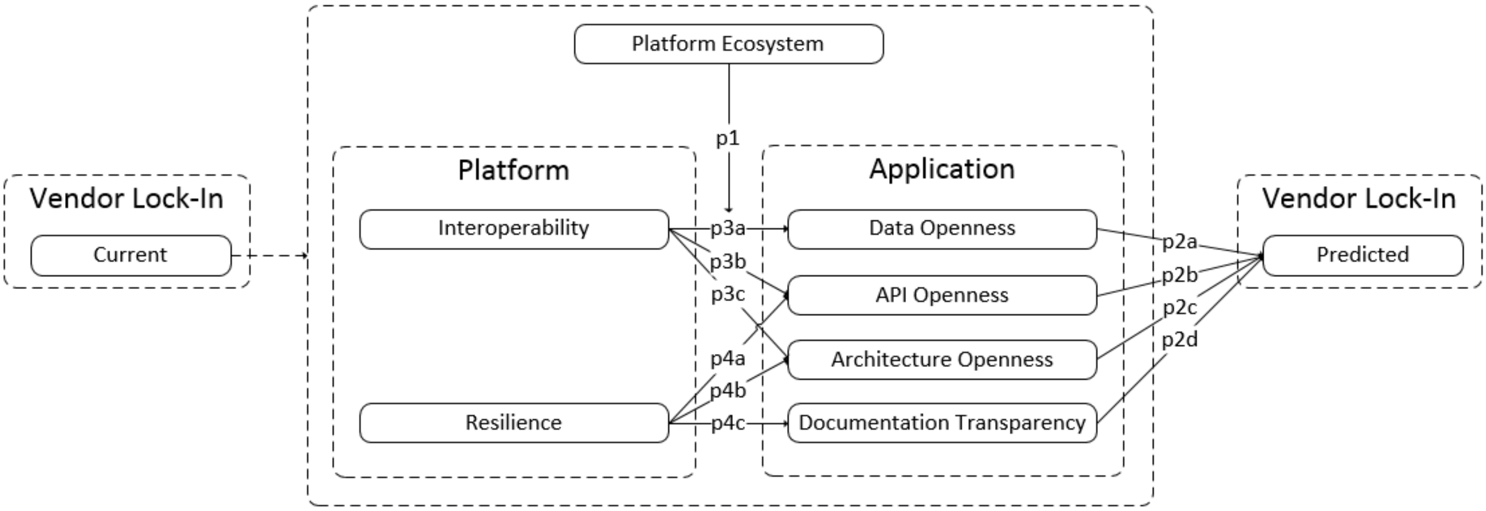

Figure 1: Conceptual Model

The developed conceptual model is largely based on Tiwana, A. (2014)'s research, expanded with a variety of literature to operationalise various elements.
Per paragraph 2.3 'Platform Ecosystem', Tiwana, A. (2014) considers there to be a platform ecosystem that moderates the relationship between platform (architecture) and the applications on this platform.
The platform determines in part the applications that will be on the platform. This happens both explicitly, by for example describing design rules (Tiwana, 2014: 7), and implicitly, by applications taking on an architecture's strengths; an open architecture can lead to more open applications (Tiwana, 2014: 93).
This development process – of platform and applications – is inspired by a certain level of current vendor lock-in, as every case is developing its platform with the explicit goal of encouraging interoperability and preventing a vendor lock-in from occurring. Therefore, the conceptual model starts with a 'current vendor lock-in', and ends with a 'predicted vendor lock-in'.

'Platform Ecosystem' draws from factors discussed in paragraph 2.3 'Platform Ecosystem'.
'Platform Interoperability' draws from factors discussed in paragraph 2.5 'Interoperability'.
'Platform Resilience' draws from factors discussed in paragraph 2.6 'Resilience'.
'Data Standard Openness', 'API Openness', 'Architecture Openness', and 'Documentation Transparency' are derived from paragraph 2.4 'Vendor Lock-In', and in this represent an amalgamation of literature.
The predicted level of vendor lock-in, the dependent variable, is taken from paragraph 2.4 'Vendor Lock-In'.

In general, the listed factors are drawn from a variety of literature in order to create a cohesive and concise model that is efficient to apply. Therefore, the proposed conceptual model is not an exhaustive list of factors, but a selection of categories thought to be the most relevant. These categories will be investigated through a multiple-case study, wherein the categories are concretised (see Appendix IV: 'Case Study Questions'). Together with the unique context and details of the case in question, this will lead to a ranking of the various aspects (e.g. 'platform interoperability is high').

Applying the conceptual model in this way will answer the fifth sub-question: "How do the smart city platform architectural factors influence vendor lock-in?". By comparing the results of the various cases in paragraph 5.6 'Cross-Case Analysis', a revised conceptual model will be proposed in paragraph 5.7 'Revised Conceptual Model', upon which a final conclusion will be drawn to answer the main research question.

4. Research Methodology

In this chapter, the methodology underlying this thesis will be defined. In order, this consists of the research approach, the research strategy, the case study design, a discussion on validity and reliability, the research methods, the data analysis, and the case selection.

4.1 Research Approach

This thesis takes a cross-sectional deductive approach to research, concerning itself with the testing of the influence of platform architectures (and other factors) on vendor lock-in at one specific point in time. No new theory will be generated (as with an inductive approach), but theory will be expanded by testing the pre-existing theory and adding weights to the individual factors.

This testing will be done by way of qualitative analysis. This allows for open-ended questions and the 'drilling down' on interviewee's responses, providing a greater opportunity for data to be collected (Mack et al., 2005). This also allows for a more flexible and iterative approach, in that the conceptual model and the questions to be asked can be refined after each case, as discussed in paragraph 4.4.2 'Internal Validity'. Further, this allows for the use of a pilot case study, as discussed in paragraph 4.4.4 'Reliability'.

The unit of analysis – the subject of a case study, that what a case is – will be the smart city platform, since smart city platforms will be compared on their propensity for vendor lock-in. The extent of this presence will be analysed by combining two fields of theoretical literature – that of platforms and that of vendor lock-in – with the practical findings from the case studies.

4.2 Research Strategy

There are multiple qualitative research strategies. Yin (2003) discusses five; experiment, survey, archival analysis, history, and case study. These methods are separated by three categories; the form of the research question, whether control of behavioural events is required, and whether the study focuses on contemporary events (Yin, 2003: 5).

The form of the research question is 'how' (… do smart city platform architectural factors contribute to vendor lock-in in the context of the smart city of Rotterdam?), which points to the research strategy of 'experiment', 'history', or 'case study' (Yin, 2003: 5-7).
Informal manipulation may occur with a case study strategy, whereas an experiment needs to account for all variables and manipulations thereof. Therefore, should control of behavioural events be required, an experiment is advised. As this research question seeks to gain greater insight into a situation as it is – it will not manipulate the situation, by for example introducing vendor lock-in to an architecture – the research strategy of 'experiment' is not advisable, leaving 'history' or 'case study' as possible options (Yin, 2003: 8).
The research question concerns itself with contemporary events, which favours the case study strategy over the history strategy. Compared to the history strategy, the case study strategy adds two aspects; direct observation of the event that is being studied, and interviews with the person involved in this event. Both of these are necessary for answering the research question. Therefore, the research strategy of 'history' is not advisable (Yin, 2003: 7-8).

As such, 'case study' is selected as the research strategy for this thesis. This makes intuitive sense as well when 'archival analysis' and 'survey' (the remaining two research strategies) are analysed.
There are no archives bearing relevant records, nor are there database with relevant variables; the goal of this thesis is to apply theory to practice, as this has not been done before. Therefore, 'archival analysis' is impossible.

Surveys could be used to apply theory to practice. However, Yin (2003) notes the following discussing the purpose of a case study: "The most important is to explain the presumed causal links in real-life interventions that are too complex for the survey or experimental strategies." (Yin, 2003: 15).
Further, Dul and Hak (2008) note that a case study is useful when the unit of analysis is complex, when scarce theory is available, and when context is important.
Smart cities are a highly complex and ongoing development. Surveys will not yield enough in-depth insight in the various architectures on a sufficiently deep level. Contextual knowledge specific for each and every situation would need to be incorporated in the survey, leading to an amount of different surveys equal to the amount of cases, which misses the point of a survey.
Therefore, 'survey' can only be used as a first step towards selecting cases, and 'case study' remains the selected research strategy for this thesis.

4.3 Case Study Design

Case studies can be classified in three categories; exploratory, descriptive, and explanatory case studies (Yin, 2003).

An exploratory case study aims to answer 'what' or 'who' questions. It is a flexible study of a new phenomenon, used when a problem is broad and not specifically defined. An exploratory case study is used to understand what is happening, and seeks new insights or assesses phenomena in a new light. Exploratory research may develop hypotheses, but does not seek to test them (Jajoo, 2014; Yin, 2003).

Descriptive case studies "examine the data closely both at a surface and deep level in order to explain the phenomena in the data" (Zainal, Z., 2007). Descriptive research defines the questions to be asked, the people to be surveyed, and the method of analysis prior to the data collection, in contrast to exploratory research. This limits the flexibility and requires specific definitions, but allows the testing of hypotheses (Jajoo, 2014; Yin, 2003).

Explanatory case studies seek to answer 'how' or 'why' questions. They concern themselves with cause and effect; how an independent variable influences a dependent variable. Explanatory research goes beyond descriptive research; the latter is primarily concerned with observation whereas the former seeks to explain the reason about what is being observed (Jajoo, 2014; Yin, 2003).

Yin (2003) notes that there may be large areas of overlap between both the research strategies and the case study categories. There are not necessarily clear boundaries between them, nor are they mutually exclusive; a case study might both be exploratory and descriptive, for example, or both a survey and a case study might be used to obtain results (Yin, 2003: 9).

Theory already exists – on platforms and on vendor lock-in – although this theory has not yet been combined and tested. Therefore, this study will apply existing theory to a new setting, a characteristic of the descriptive and explanatory case studies.
Independent variables (the platform architectures and related factors) and a dependent variable (the phenomenon of vendor lock-in) have been defined before testing the theory, with the intention of explaining which of the architectural factors affect the phenomenon vendor lock-in to which extent. Given the stated intent, this is more a characteristic of explanatory case studies than it is of descriptive case studies.
Finally, the research question is formulated as a 'how' question, which also fits the explanatory case study design.

Therefore, this study should primarily take the shape of an explanatory case study design.

4.4 Validity & Reliability

Yin (2003) identifies four problems with case studies, that impact the validity and reliability of results obtained by case studies. Further, a variety of case study tactics are also identified, meant to aid the construct validity, internal validity, external validity, and reliability. First, the four problems will be discussed:

For one, a lack of rigor is often seen in the execution of a case study, caused by not following systematic procedures. An underlying reason is that the case study had (at the point of writing, in 1994) been covered by fewer works of methodological literature than the other research strategies (Yin, 2003: 10).
By following the procedures set up by 'Case Study Research Design and Methods' (Yin, 2003) and cross-referencing this with more recent works (e.g. Jajoo, 2014; Zainal, 2007), the identified lack of rigor is addressed.

A second problem is that case studies provide little basis for scientific generalisation. Yin (2003) compares this to the research strategy of the experiment, and notes that scientific facts are usually based on multiple experiments that have replicated one phenomenon under multiple conditions. In this case, experiments are indeed generalisable, although to theoretical propositions instead of populations or universes (Yin, 2003: 10).
Similarly, instead of selecting one case to study, this thesis will select multiple cases, and thus use a multiple-case study approach. As the research question concerns itself with expanding a pre-existing theory instead of enumerating frequencies – that is, analytic generalisation instead of statistical generalisation – the results from this thesis should have sufficient basis for scientific generalisation (Yin, 2003: 10).

The third problem is that case studies can take too long and result in massive, unreadable documents. Yin (2003) notes that this confuses the case study strategy with for example ethnography, which generally requires a long time in the 'field' and could as such result in numerous pages of detailed observational evidence (Yin, 2003: 11).
These concerns can be alleviated by noting that this thesis is part of a university programme. This includes adhering to deadlines (alleviating the problem of taking too much time) and following a structured approach to both this study as to the lay-out of this document presenting the results of the study (alleviating the problem of massive, unreadable documents).

The fourth problem that Yin (2003) identifies, is that the execution of a case study relies on the investigator's ability to do good case studies (Yin, 2003: 11).
No solution is offered, and being but a twenty-three year old student, this investigator bears no illusions that he would somehow be a natural talent for doing case studies. However, as noted, this thesis is part of a university programme, including a coach, a co-reader, and a Master thesis committee. It may be assumed that a passing grade for this thesis inherently necessitates the ability of the investigator to do a case study with at least some modicum of quality.

Beyond these four problems, Yin (2003) also identifies a variety of case study tactics meant to aid the construct validity, internal validity, external validity, and reliability (Yin, 2003: 34). These are summarised in Appendix V: 'Validity & Reliability'. A detailed description of each tactic can be found in the next four paragraphs.

4.4.1 Construct Validity

Construct validity concerns itself with the operationalisation of the concepts that are being studied (Yin, 2003: 34-36). For this thesis, those are the architectural factors and the phenomenon of vendor lock-in. It is important to not only select and define the specific concepts that are to be studied, but also to demonstrate that the selected measurements of these concepts reflect the actual reality. In specific:

Does the way of how the presence of an architectural factor is measured, reflect the reality of to which extent this architectural factor is present?
Does the way of how the presence of vendor lock-in is measured, reflect the reality of a vendor lock-in having occurred?

Yin (2003: 35-36) notes three ways of ensuring construct validity; using multiple sources of evidence, establishing a chain of evidence, and having interviewees review a draft case study report.

The first way of ensuring construct validity is by using multiple sources of evidence, as case studies inherently involve a wide variety of evidence. Using multiple sources of evidence allows for triangulation; employing multiple methods to verify the results obtained from one method. Specifically, this allows for the triangulation of data sources. Another type of triangulation is that of gathering multiple perspectives on one case, by for example interviewing a business manager and an IT manager. Using triangulation allows for converging lines of inquiry (Yin, 2003: 97-98).

Sources of evidence consist of, for example, documentation, archival records, interviews, direct observations, participant-observation, and physical artefacts (Yin, 2003: 85-96).

It is doubtful that archival records will be relevant for this specific case study, unless a visualisation of platform architectures over the years might yield insights pertaining to this thesis's research question.

Interviews will most likely be the most important source of evidence for this case study. Therefore, the weaknesses of interviews warrant addressing. Yin (2003: 86) notes four: Bias due to poorly constructed questions, response bias, inaccuracies due to poor recall, and reflexivity; an interviewee saying what the interviewer wishes to hear.
The bias due to poorly constructed questions will be minimised by the case study protocol (Appendix VI: 'Case Study Protocol'), which contains the case study questions. Further, a pilot case study will be held, which would reveal potential issues. Finally, this thesis's coach and co-reader will be asked to judge the case study before its practical execution.
Response bias can be minimised by, for example, using clear language and framing questions in a neutral, unbiased way (Ziniel, n.d.). This ties in with the methods given to minimise the bias due to poorly constructed questions.
Inaccuracies due to poor recall will be addressed by recording the interview, provided that permission is given by the interviewee. Further, notes will be taken during the interview, and the interview will be ended with a recap to ascertain that the interviewer properly understood the interviewee.
Reflexivity is a topic that has been addressed in multiple ways (e.g. Finlay, 2002). Begoray (2012) defines reflexivity as "a researcher's ongoing critique and critical reflection of his or her own biases and assumptions and how these have influenced all stages of the research process". It involves assigning meanings and relating these to specific contexts, and requires researchers to "articulate their awareness of the interconnectivity between and among themselves, the participants, the data, and the methods they use to interpret and represent their findings." (Begoray, 2012). This is done

through a variety of means, such as by the writing of chapter 4. 'Research Methodology', or by discussing and inferring meaning from the case studies.

Direct observation will ideally be a component of the interviews, in that ideally the interviews will be held physically. However, no interviewee will be followed for a period of time with the intent of observing common behaviour and the day-to-day occurrences.

Participant-observation is comparable to direct observation, but whereas the latter is more passive, participant-observation requires the investigator to take a more active role (e.g. taking on a job in one of the selected cases). This might produce deeper or richer results, but also more biased results (Yin, 2003: 93-96). This will not be done during this case study.

Finally, a physical artefact, being "a technological device, a tool or instrument, a work of art, or some other physical evidence" (Yin, 2003: 96), is deemed to be unlikely to be found relevant for this case study.

The second way of ensuring construct validity (as well as reliability) is by establishing a chain of evidence (Yin, 2003: 36). This should allow anyone reading about this case study to identify the steps taken from research question to conclusion, and from conclusion to research question (Yin, 2003: 105-106). This was addressed when discussing the problem of massive, unreadable documents; this thesis is created as part of a university programme and aims to be a comprehensive and logically structured document.

The third way of ensuring construct validity consists of interviewees reviewing a draft case study report (Yin, 2003: 36). This corroborates the facts and evidence presented in the case study, and can offer valuable insights to refine the case study in general (Yin, 2003: 159-160). Because of the confidential information that will be gathered, interviewees will only be allowed to review their own case.

4.4.2 Internal Validity

Internal validity is only relevant for causal studies, which excludes descriptive or exploratory case studies, but includes explanatory case studies (Yin, 2003: 36). Given that this thesis employs an explanatory case study design, internal validity is relevant. Internal validity concerns itself with establishing a causal relationship; whether there is no confounding variable that influences the relationship between the dependent and the independent variable, and whether an inferred causal relationship actually exists.

Yin (2003: 36) describes four ways of addressing internal validity; pattern matching, explanation building, addressing rival explanations, and logic models.

Pattern matching involves the comparison of a predicted pattern with the empirically observed pattern (Yin, 2003: 116-120). This is in part the purpose of chapter 3. 'Conceptual Model'. Ideally, however, this would be a statistical endeavour. Numbers – e.g. 'architectural factor #1 contributes to vendor lock-in with 0.81' – would thus have to be distilled from earlier cases and applied to later cases, within this multiple-case study, as no such numbers exist yet. However, a categorical approach will be used for this thesis.

Explanation building is a specific type of pattern matching, involving the refinement of a theoretical proposition after each case study, thereby gradually building an explanation (Yin, 2003: 120-122). The initial theoretical proposition for this case study is the conceptual model found in chapter 3.

'Conceptual Model'. As this theoretical proposition is refined, a risk is that the final answer may not be an answer to the original research question. A case study protocol has been established (see Appendix VI: 'Case Study Protocol') in order to alleviate this risk. Explanation building lends itself to a cross-case analysis, which is included in paragraph 5.6 'Cross-Case Analysis'.

Addressing rival explanations is one of three analytical strategies that can be used; the other two being to rely on theoretical propositions and to develop a case description (Yin, 2003: 111-115). Yin (2000) identifies several kinds of rival explanations, that seem to align with statistical literature on how the measured effect an independent variable has on a dependent variable may be wrong. For example, a mediating variable may explain the effect better, a moderating variable may affect the strength of the effect, or a covariate may independently predict the dependent variable (Saunders and Lewis, 2004). This will be kept in mind during the case analyses, but should not form the basic analytical strategy of this thesis. No studies have yet been done on the theoretical proposition underlying this thesis, so rival explanations can only be formed as part of refining the theoretical proposition.
With the strategy of relying on theoretical propositions, a case study is built on certain propositions that are reflected in, for example, the used literature, the formulated research question(s), and the collected data. The theoretical propositions that underlie a case study thus narrow the focus of a case study, and ideally lead to the most relevant sources being used. This is in specific the purpose of chapter 1. 'Introduction' of this thesis, but can in general be found throughout the entirety of this thesis's structure.
The final strategy, that of developing a case description, is less preferable, as it is a descriptive approach (Yin, 2003: 114). It would, in this thesis's author's opinion, conflict with addressing the problem of massive, unreadable documents, as discussed in paragraph 4.4 'Validity & Reliability' and paragraph 4.4.1 'Construct Validity'.

Logic models can be seen as another type of pattern matching, involving a chain of cause and effect where the original dependent variable (the first effect, caused by the first independent variable) becomes the independent variable of a new dependent variable; the effect causes a new effect (Yin, 2003: 127-133). Logic models will not be used for this case study, as the question to be answered revolves around the influence of architectural factors on vendor lock-in, and not on, for example, the underlying factors that lead to these architectural factors. It might be that these underlying factors – and not the architectural factors themselves – explain the occurrence of vendor lock-in, but this is part of addressing rival explanations, as expanded upon in the previous paragraph.

4.4.3 External Validity

External validity concerns itself with generalising results beyond the case study the results were found in (Yin, 2003: 37). As noted when discussing the problem of scientific generalisation, 'generalising', in the context of case studies, refers to analytic generalisation (the generalisation of a set of results to a broader theory), not to statistical generalisation (enumerating frequencies).

To account for external validity, the theory formulated as part of the research question (paragraph 1.2 'Problem Statement') and the conceptual model (chapter 3. 'Conceptual Model) should form the basis for multiple case studies. Further, this theory must be tested by replicating its findings across multiple cases, so as to ensure the theory's generalisability (Yin, 2003: 37). Generalisability thus depends on the cases selected, but this does not need to be a random selection in order to be generalisable (Flyvbjerg, B., 2003: 425-426). This is why this thesis employs a multiple-case study design. If a plurality of cases yield the same results, just as a plurality of experiments can yield the same results, these results can be generalised to the broader theory underlying the cases or experiments.

4.4.4 Reliability

Reliability concerns itself with minimising errors and biases; that future researchers might replicate this multiple-case study exactly as it is described, finding the same conclusions to support the same theory (Yin, 2003: 37).

To account for reliability, Yin (2003: 57) describes five aspects; personal skills, training for a case study, a case study protocol, the screening of case study nominations, and a pilot case study. All these factors influence to what extent this case study process is replicable in the same circumstances to yield the same results.

Personal skills were briefly discussed with the problem of the investigator's ability to do good case studies. However, lacking both an (objective) assessment of personal skills and a means of improving personal skills, this is probably the weakest and most subjective point when it comes to reliability.

Similarly, training for a case study might consist of seminars given by 'senior investigators', which is not the case for this multiple-case study. However, defining the questions to be asked (Appendix IV: 'Case Study Questions') and developing the case study design (paragraph 4.3 'Case Study Design') are also part of this training, so only minimal further effort would be needed to fully satisfy this aspect (Yin, 2003: 62-64).

A case study protocol "is a major way of increasing the reliability of case study research and is intended to guide the investigator in carrying out the data collection" (Yin, 2003: 67).
It consists of four parts; an overview of the case study project (including, for instance, the theoretical framework for the case study, or relevant literature), field procedures (data collection procedures), case study questions (topics to be discussed), and an outline of the case study report to be used (data format, documentation, bibliography) (Yin, 2003: 69).
The case study protocol is included in Appendix VI: 'Case Study Protocol'.

Screening of case study nominations is a non-extensive procedure done to ensure that the cases to be studied are both accessible and relevant (Yin, 2003: 77-78). It is discussed as part of paragraph 4.6 'Case Selection'.

The pilot case study is the first of the selected cases to be studied. It can help refine data collection plans, clarify concepts, or offer other valuable lessons or insights, to be used when studying the other cases. It is, however, one of the cases to be studied and to be included in this thesis's results (Yin, 2003: 78-80). The pilot case study is also discussed as part of paragraph 4.6 'Case Selection'.

Finally, as discussed in paragraph 4.4.1 'Construct Validity', a chain of evidence also adds to the reliability.

4.5 Research Methods

There are multiple research methods (or, data collection methods) for explanatory case studies. For example, as noted by Saunders and Lewis (2009); interviews, observation, documentary, analysis, and questionnaires. Similarly, Yin (2003) notes six commonly used sources of evidence, as discussed in paragraph 4.4.1 'Construct Validity', further noting that a complete list would be too extensive to include.

Initially, a questionnaire (Appendix III: 'Questionnaire') was sent out to get a broad-level overview of where smart cities within the EU are at the moment. The purpose of this is twofold:

One, in line with chapter 1. ‘Introduction’, it provides a convenient format for sharing information about and between the many smart cities. As such, it is a questionnaire transcending this thesis, created cooperatively by a multitude of people.
Two, the questionnaire is a useful tool to select interesting cases; for instance, if cases appear to be similar based on the questionnaire, a case study may be conducted to test if they are actually similar, and if so, then the results should be similar as well (to verify the conceptual model).
However, because of a delay in response time, cases were selected largely without the help of the questionnaire.

For the selected cases, semi-structured interviews – in-depth interviews with open questions – were used, ideally with both the interviewee and the interviewer physically present so as to allow for observation. This allows the interviewee to provide valuable insights that the interviewer might not have been able to predict (Blumberg, 2008). Ideally, every case will be studied by interviewing two interviewees, to allow for triangulation.

A few general field procedures have been established:

- All interviewees will know the context of this case study (that is, a summary of chapter 1. ‘Introduction’ and chapter 3. ‘Conceptual Model’) before the start of the interview.
- All interviewees will be asked whether the interview may be recorded, knowing that the recording will not be shared beyond this thesis’s coach and co-reader without the interviewee’s documented (e.g. by email) permission.
- If recording the interview is not allowed, notes will be made during the interview by the investigator (on the investigator’s laptop, turned sideways so as to not be positioned in between the investigator and the interviewee, if a physical meeting).
- Interviews will ideally be one-on-one conversations in secluded and quiet spaces (e.g. an empty office of the interviewee’s company, if a physical meeting).
- After the interview, a description of the case (similar to the results of chapter 5. ‘Case Studies’) and a colour-coded variant of Appendix IV: Case Study Questions (to indicate how and why the case scored on each topic) will be submitted to the relevant interviewee(s). This enables the interviewee(s) to correct certain interpretations or add nuance.

A list of questions asked can be found in Appendix IV: ‘Case Study Questions’. This improves this thesis’s reliability, allowing others to reproduce the case studies in a similar manner, and also improves this thesis’s validity, by ensuring that the interviewer gathers and measures the same kind of data about each case study.
The questions should not be asked explicitly, but are formulated to give insight into what topics were covered in which ways during the case study interviews. Not every case study should necessarily result in an explicit answer to all of the questions, but the underlying theme should be touched upon to provide deeper insights beyond what a questionnaire can achieve.

Per paragraph 4.4.4 ‘Reliability’, a pilot case study is conducted to ensure a baseline standard of information gathering.

4.6 Case Selection

Ideally, a wide variety of cases would be chosen, each being a multi-sided platform intended to be open. This range of cases would account for both similarity and dissimilarity (atypical or extreme cases are often richer in information, per Flyvbjerg, B., 2003) in the following aspects:

- The current smart city development approach;
- The ideal outcome of the smart city development process;
- The architectural framework underlying the smart city;

- The estimated level of vendor lock-in.

In order to gain insight into these aspects, a questionnaire detailing these aspects was made and sent out on the ninth of April, 2018, to nine EU-wide smart city initiatives (see Appendix III: 'Questionnaire'). However, because of a delay in response time, cases were selected largely without the help of the questionnaire.

Ten potential cases were identified based on the conceptual model and the underlying propositions, a process advised by Yin (2003: 77-78). Five cases responded positively, and as such, five case studies were held (see also Appendix II: 'Interviews', IX to XIV):

Case	Interviewee(s)	Function	Reasons
Rotterdam	Roland van der Heijden	Product Manager Digital City	Follows ESPRESSO framework Participant in EU Ruggedised
Amersfoort	Bauke Keulen Janette van Dijk	Team Manager and Strategical Advisor Information Management Project Manager Smart City	Follows FIWARE framework Interesting as a comparison with Utrecht
Utrecht	Thomas Kruse	Strategy Advisor Business Management	Follows FIWARE framework Participant in IRIS
Glasgow	Gavin Slater Ciaran Higgins	Group Manager – City Energy & H2020 Ruggedised Lead Director at Derryherk Limited	Follows ESPRESSO framework Participant in EU Ruggedised Interesting because of its vendor lock-in awareness
Umeå	Carina Aschan	Project Manager RUGGEDISED	Follows ESPRESSO framework Participant in EU Ruggedised

Table 1: Case Study Overview

4.7 Data Analysis

Accounting for the potential issues concerning structure and length raised in the previous paragraphs, Yin (2003: 111) recommends to conduct within-case analyses and a cross-case analysis. This will result in a data matrix to summarise the results in an orderly manner, an approach established by Miles and Huberman (1994).

The within-case analysis is conducted for every case, and translates the gathered information into categorical values ('low', 'medium', or 'high') for each of the dependent and independent variables. 'Medium' values can be rounded up or down (to 'high' or 'low') where appropriate for analytical purposes. This value is based on the questions outlined in Appendix IV: 'Case Study Questions'; if a variable constitutes of nine questions of which six are answered positively, this variable will likely be ranked as 'high'. However, this is not a hard rule; the richer context of the case study can influence the eventual result, and the aforementioned variable could therefore theoretically be ranked as 'medium' or 'low'.
A colour-coded variant of Appendix IV: 'Case Study Questions' (to indicate for which particular question which city has which value) is available for every case on request.
These analyses are combined in the cross-case analysis. Should most of the independent variables be 'high', then the corresponding dependent variable should also be 'high'. If this occurs in a majority of the cases investigated, the relevant proposition is upheld.

Per paragraph 4.4.1 'Construct Validity', each case study report will be reviewed by the interviewee. This aids the case study's construct validity (Yin, 2003: 36) and ensures that the gathered information is correct, free of misinterpretation. It further allows the interviewee to potentially contribute new information. Although Miles (1979) and Yin (1981: 8) raise some objections, the recordings of the case studies will provide an objective reference.

5. Case Studies

This chapter contains the case studies conducted to validate and refine the proposed conceptual model. With these, it will answer sub-question five: "How do the smart city platform architectural factors influence vendor lock-in?".

First, a numerical summary of the case studies is presented. The table shows the variables (e.g. 'Platform Interoperability') with the number of questions (Appendix IV: 'Case Study Questions') between brackets (e.g. 13). Then, for each case, the amount of questions answered in a manner corresponding to 'High', 'Medium', or 'Low' are shown (e.g. for Rotterdam, for 'Platform Interoperability', this is respectively 10, 0, and 1). The 'Platform Ecosystem' and 'Vendor Lock-In' variables are not shown, because they are not adequately captured with numerical information (e.g. the platform development approach is a descriptive story that was not broken down in numerous questions).
As noted before, these questions were not literally asked, but the answers were distilled from the case studies. As also noted before, although this numerical information does form the basis for the level of variables (e.g. Rotterdam scores 'High' on 'Platform Interoperability'), contextual information from the case study not captured with these predefined questions can change this level.

Variable (n)	**Rotterdam (H/M/L)**	**Amersfoort (H/M/L)**	**Utrecht (H/M/L)**	**Glasgow (H/M/L)**	**Umeå (H/M/L)**
Interoperability (13)	10 / 0 / 1	11 / 0 / 0	9 / 1 / 2	8 / 2 / 2	4 / 3 / 3
Resilience (7)	4 / 0 / 0	0 / 3 / 0	3 / 0 / 0	4 / 0 / 0	1 / 3 / 0
Data Standard Openness (18)	10 / 1 / 3	9 / 1 / 2	5 / 4 / 1	10 / 0 / 0	7 / 5 / 1
API Openness (8)	2 / 1 / 5	4 / 2 / 1	3 / 1 / 2	3 / 1 / 3	2 / 1 / 2
Architecture Openness (4)	0 / 1 / 3	1 / 2 / 0	3 / 0 / 0	0 / 2 / 1	0 / 1 / 0
Documentation Transparency (4)	0 / 0 / 3	4 / 0 / 0	1 / 0 / 0	2 / 0 / 0	2 / 0 / 0

Table 2: Case Study Overview

Below, the five within-case analyses are presented in chronological order, followed by the cross-case analysis and the revised conceptual model.
The within-case analyses start with a short paragraph regarding the reason, date, location, and interviewee(s) of the case in question. This is followed by a table with the variables, their measured level, and a single indicator to keep the table concise (more indicators are available upon request). Finally, a narrative of the case is presented, structured similarly for each case (depending on the unique context). Broadly speaking, the structure is as follows; what is the smart city in question, what is the platform (explicitly including the 'Platform Ecosystem' variables), the five 'Application Openness' variables, and vendor lock-in.

5.1 Rotterdam

This thesis is conducted at the Rotterdam School of Management, in cooperation with the municipality of Rotterdam, and in the context of the EU Ruggedised initiative which includes Rotterdam. This makes the smart city of Rotterdam the most accessible case study, and therefore, Rotterdam has been chosen for the pilot case study (Yin, 2003: 79-80). This case study was conducted on the 24th of April, 2018, with Rotterdam's 'Product Manager Digital City' in 'De Rotterdam'.

Variable	**Level**	**Indicator**
Ecosystem		
Development Approach	Top-down	"And what we try to do is to create some kind of generic

		platform connector."
Envisioned Result	Digital Community	"That's also our role, as a municipality we are not the primary party to develop an API, but we are the primary party to develop some kind of field in which those APIs can flourish."
Architectural Framework	ESPRESSO	"I really believe in the approach of ESPRESSO."
Platform		
Interoperability	High	"What are the minimal system requirements, and try from there much more modular development and more flexibility."
Resilience	Medium (High)	"What I think is also part of resiliency is that you make your data in such a form that it can flow in all kinds of directions."
Application		
Data Standard Openness	High	"You need to use open data standards."
API Openness	Medium (Low)	"Accessing an API is depending on the API developer, what kind of rules he attaches to it."
Architecture Openness	Low	"Yes." (to the question: "I can require proprietary things or runtime programs and put it on the platform?")
Documentation Transparency	Low	"It is now also for a large extent unstructured because we are learning."
Vendor Lock-In		
Current	High	"I think in that sense we are even more vulnerable."
Predicted	Low	"This [proposed development of the Digital City] is aimed at preventing vendor lock-in. The ESPRESSO approach is also explicitly aimed at this."

Table 3: Case Study Rotterdam

A smart city revolves around connection. There are many different smart city-related solutions, but they all work in their own silos without being aware of – being connected to – other such solution. This leads to problems regarding unstandardised input and unusable output. A modern smart city initiative is therefore about combining smart city solutions (but the concept originated from technical companies, providing technical solutions).

For this, an iterative process between demand and supply is needed. The demand exists in the form of information questions – such as business problems – while the supply exists in the form of data from silos constructed to deal with one particular question. A generic platform connector is needed to enable Rotterdam to use all kinds of data to gain all kinds of information, by using the data as an input for different applications and services. Therefore, the focus of Rotterdam lies on delivering the platform.

This platform will take the shape of a marketplace where supply and demand for data can meet, given agreements regarding under which conditions suppliers want to share their data. As such, the initial focus of this platform is on data, but in the future, this will expand to include services and applications. It is envisioned as a natural growth; combinations of data lead to a service, and combinations of services lead to an application. Rotterdam wants to develop an urban platform, because it is thought that services (information) – not merely data – attracts people, but the first step towards that is the development of an urban data platform.

Rotterdam, as such, aims to develop a community on this platform. The platform will be freely accessible to everyone – it gives access to the city, in a sense – but the content put on the platform can be subject to whatever requirements the supplier of the content decides on. The platform will therefore operate on free market principles, and a goal of this platform is to encourage the (independent) development of APIs (i.e. services). As such, users do not have a 'contract' with the city of Rotterdam, but with the suppliers on the platform.

However, data put on the platform is open data, and it is intended for users to be able to see exactly which kind of data is available of them and to, if desired, stop this data collection. Citizens should be in charge of their own data, which can include commercial models for citizens to sell their own data. Rotterdam, as such, focuses on data, when it comes to openness. This is evident from this case study's results, with 'API Openness', 'Architecture Openness', and 'Documentation Transparency' scoring lower than 'Data Standard Openness'.

Rotterdam follows the ESPRESSO approach, including the MIM-thoughts on API strategy, standardised data models, and open data standards. Rotterdam further intends to adopt the suggestions of Rustenburg (2017), which concerns itself with API strategies, and further notes documentation as being of key importance.

Because Rotterdam is a large city, with many large departments, Rotterdam suffers more than others from vendor lock-in. Complex communication channels and many potential entry-points for a vendor lock-in mean that switching costs are higher than for most other smart cities as well.
However, the ESPRESSO approach – specifically the thoughts regarding PPIs and MIMs – explicitly seeks to prevent vendor lock-in. Rotterdam also views data standard openness as a key factor for preventing vendor lock-in, and accordingly scores high on this factor.

5.2 Amersfoort

Amersfoort was chosen as a case because it is a smart city using the FIWARE platform. The case study was conducted by phone on the 14th of May, 2018, with Amersfoort's 'Team Manager and Strategical Advisor Information Management'. To verify the results, a second interview was held by phone on the 23rd of May with Amersfoort's 'Project Manager Smart City'.

Variable	Level	Indicator
Ecosystem		
Development Approach	Top-down	"We were experimenting with what to put on a data platform [...] and had thought 'maybe there are app developers who want to use this', but it didn't really amount to anything as it was very demand-driven; we published this to see if there was any demand for it."
Envisioned Result	Digital Community	"We hope for the participation of citizens, that they realise 'hey, there is data, that is interesting, I can use this', and we also hope for the local business [...] to realise 'hey, that data is gold, I can use this'."
Architectural Framework	FIWARE	"We already have a FIWARE platform, which is our open data platform on which we have published a number of data collections."
Platform		
Interoperability	High	"We all benefit from smart city initiatives not being something local, but that if you make something, that it is possible to scale this up to a national level."
Resilience	Medium	"I think that is a good point of attention. These are things that play a role during the development of the architecture." (referring to redundancy)
Application		
Data Standard Openness	High	"It's an open data platform, so it has to be open; open standards, open data – if a company wants to put its closed data on it, that is useless."
API Openness	Medium	"One of the most important demands of a tender is that you get a supplier [...] that aligns with the vision of the municipality on open standards."
Architecture Openness	Medium	"Take care that what you do is scalable across municipalities."
Documentation Transparency	High	"We always put those kind of facts in our tender documents." (referring to open standards)
Vendor Lock-In		
Current	High	"The current arrangement is strongly bound to suppliers [...] they deliver a fully vertical solution, so you can't just view the data and couple it to other things, that requires mutations and agreements with them."
Predicted	Low	"Yes, because all suppliers realise that municipalities and other users are demanding different things." (to the question: "And do you see that happening, that it will become more open?")

Table 4: Case Study Amersfoort

A smart city revolves around the participation of its citizens: “The paragraph ‘participation’ is better represented compared to the technical approach.“ Citizens won’t be interested in every single aspect of what a smart city entails, and the data to be gathered and published should be decided from a citizen-centric perspective. For instance; a citizen wants traffic congestion to be solved, and presumably doesn’t care where the sensors are placed to measure this. On the other hand, placing sensors in public spaces to measure humans is an ethical question citizens should be involved with. Amersfoort views it as the moral duty of a municipality to discuss this with the involved parties. As such, Amersfoort is both reaching out to citizens and to its own departments, to foster closer cooperation, but this is very new and works on ad hoc basis. For example, no internal data management standards have yet been defined. However, Amersfoort is conducting small-scale pilots to prepare itself for the future, regarding such ethical questions, governance and ownership, and the volume of data to be processed.

Amersfoort works in close cooperation with other municipalities, such as Hilversum, Amsterdam, Eindhoven, or Utrecht. Amersfoort further aligns with, for example, the EBU (Economic Board Utrecht), the (translated) ‘Municipal Acquisition Prerequisites for IT’ (Gemeentelijke Inkoopvoorwaarden Bij IT; GIBIT), and the Dutch ISO institution, cooperating on a variety of matters relating to interoperability, scalability, and open data. However, Amersfoort also finds it important for both parties to realise value; that is, Amersfoort does not wish to enter binding contracts that ‘force’ parties to cooperate together, even if it turns out that a certain project might be less valuable than first expected for one of the parties. Definitions of what a smart city is also differ between parties, but Amersfoort sees a common theme in that they involve technology, societal issues, and co-creation with the city (involving companies, citizens, and knowledge institutions such as universities)

The eventual smart city platform of Amersfoort, on which to publish the data, might be the FIWARE platform, but this is not yet certain. Ideally, a consortium of companies would realise this platform, but Amersfoort is still in an exploratory phase. Conceptually, the platform consists of infrastructure (such as lampposts), sensors (to put on the infrastructure), and data (with which to develop services). The platform will allow users to put data and applications on it for commercial purposes, which is seen as a concession; companies pay to place sensors (on for example the lampposts), which puts data on the platform, and then allows users to use this data to create applications and services.
Currently, two platforms exist; one data platform that multiple municipalities use, and a platform that visualises data on a map, exclusively developed for and used by Amersfoort. These platforms allow everyone to pull data from it, but only allow the municipalities (or municipality) to put data on it, which they do according to pre-defined formats, making both platforms interoperable. All platforms should be easily accessible, potentially only requiring an account for certain large volumes of data so as to prevent a DDoS attack. Privacy is an important concern throughout all of this; no data should be able to be traced back to a specific individual.

Amersfoort usually does not develop its own applications; it acquires them together with other municipalities or companies. This does mean that Amersfoort cannot always decide which exact standards to use, besides ensuring that whichever standard is used is an open and internationally-recognised standard. However, Amersfoort takes care to use suppliers that have proven their capabilities and vision regarding open standards (and ideally open source as well). Further, because of the close cooperation with the aforementioned parties, interoperability, portability, and scalability are key points for this. It is the role of the EBU to ensure scalability to other (municipalities’) platforms.

Amersfoort values transparency in its tenders and acquisitions. It follows the GIBIT, as mentioned, and as such, takes care to document requirements and an exit strategy (amongst others). This is all specified within the GIBIT, and takes place during the acquisition process, before a final contract has been signed. However, not every exit strategy is equally adept at preventing vendor lock-in; for Amersfoort, it is not so much about getting rid of a supplier, than it is about gaining access to file formats and ownership of data, ensuring portability. Because Amersfoort is still in an exploratory phase, questions regarding the ownership and usage of data have not been fully answered yet, but Amersfoort intends to make the answer of these questions requirements when requesting tenders.

Amersfoort currently experiences vendor lock-in through fully vertical solutions, that require the suppliers' permission before Amersfoort is allowed to for example use the data in different ways. However, Amersfoort suspects that these kinds of arrangements will become less common as suppliers realise that every customer wants to do different things, and that it thus might be profitable to develop more flexible solutions so as to reach more potential customers. Amersfoort will demand this kind of flexibility for any future tenders, to prevent vendor lock-in. Internally, silo-thinking is expected to decrease as well, as different departments start working closer together and as citizens become more involved.

5.3 Utrecht

Utrecht was chosen as a case because it is a smart city using the FIWARE platform. Although part of the IRIS initiative, it cooperates with Rotterdam and EU Ruggedised in the context of this thesis (for example, Utrecht uses the EIP-SCC framework as well). The case study was conducted by phone on the 18th of May, 2018, with Utrecht's 'Strategy Advisor Business Management'.

Variable	Level	Indicator
Ecosystem		
Development Approach	Bottom-up	"We start from the challenges, and of course we also address some generic aspects […] and we try to make the crossover to different challenges from the more generic aspects of IT."
Envisioned Result	Data Market	"It's really just a marketplace for publishing data and making data transactions possible between different stakeholders."
Architectural Framework	FIWARE	"[…] that is now in place for the open data platform is FIWARE-based […] Civity is the party that delivers the innovation platform, they are also a partner in the IRIS project, to develop the city innovation platform, and since the FIARE concept is open source and open standards, we are going with that solution for the platform that we envision."
Platform		
Interoperability	High	"[…] in which we try to make best practices on developing these urban platform standards that are used for interoperability."
Resilience	High	"Within the city innovation platform you've got different components like the context broker or onboarding functionality, which are elements of the data market as a whole […] so in that way I would say it's a loosely coupled system."
Application		
Data Standard Openness	Medium (High)	"The marketplace has to be open and accessible for all parties that want to use or share the data, so no exclusivity in access to the marketplace, the openness with regards to the data is of course restricted, it depends on the parties who share the data and under what circumstances data can be used. It's not open access to the data, it's open access to the catalogue."
API Openness	Medium	"If you have your own sensor network, with your own API in that network, you could publish in a catalogue your data […] you can make a referral to the API which is in another place, but you can support the data transaction within the platform."
Architecture Openness	Medium (High)	"The platform is now hosted on OpenStack, that is where the application components […] to deliver the services, and OpenStack is open source and open standards based."
Documentation Transparency	Medium (High)	"In our procurement policy we now have some aspects that have to do at least with data and data ownership, in

		which we remain in control of the data, and in some cases […] the owner of the intellectual idea of the source code.”
Vendor Lock-In		
Current	High	“You could say there is a vendor lock-in. It is very costly to switch […] a lot of vendors who are working for the government market, they own the IP on the software, they’ve done the data modelling, so you’re really dependent on those suppliers to make your application work.”
Predicted	Low	“With the data platform now we are using open source, open data, so the exit strategy is quite obvious.”

Table 5: Case Study Utrecht

A smart city is part of how to tackle challenges facing the city of Utrecht; Utrecht will be growing by approximately 20% in ten to twenty years, making it the fastest growing city in the Netherlands. Current policies regarding areas such as energy, mobility, or health, are not enough to support this growth, and that is where the smart city approach comes in. Working up from these individual challenges (use cases), generic aspects within the digital infrastructure are also addressed, so that other use cases can also be addressed with these generic aspects. Key themes throughout all these use cases and the development of a smart city are innovation, the digital transformation, and a data-driven economy.

This approach leads to multiple platforms. As Utrecht notes in its questionnaire response: “UDP have to be Federated to other UDP. Several frameworks, architectures are available to support this. A top down approach will be beneficial to creating the needed interoperability.” Therefore, the initial development approach is bottom-up, but eventually, in order to connect the multiple platforms (EU-wide, even), a top-down approach will be beneficial.

Currently, Utrecht maintains various data platforms. For instance, it has a small platform for its sensor network, and is working on a city innovation platform that originates from the energy transition use case. This last platform will also be used for e.g. mobility or health use cases. It currently exists as a marketplace to publish data on and to facilitate data transactions between individual citizens, households, or companies. This data can then be used in the users’ own application platforms. Data can also be published by referring to an external API, merely publishing what you offer in the catalogue and using the marketplace to support the data transaction, but not putting the data itself on the platform. However, Utrecht is not the party that provides the platform; Utrecht develops policies for it while Civity develops the platform (in accordance with Utrecht’s legislation). In the end, the various data platforms (those of Utrecht, and those outside of Utrecht) should be federated across different countries, to create a single digital marketplace for data services in the EU. This could possibly happen through the DCAT Application Profile (a specification based on data catalogue vocabulary), which is the intellectual property of the EU and a component within FIWARE.

Utrecht cooperates with national and international parties (municipalities, SDOs, and private parties) to create best practices (e.g. standards regarding interoperability or a reference architecture) on how to develop urban platforms. Utrecht does want publishers of data to use industry standards for publishing data (open APIs, billing), and also strives for standardisation regarding semantics and syntax of data (i.e. metadata, a standardised lexicon). However, Utrecht doesn’t manage this directly, but instead hopes that private parties will align with the SDOs of their respective industries, letting the free market manage this (because it makes sense for organisations to adopt such standards).

Utrecht has stepped in to help develop these kind of platforms, but its main interest is in facilitating a data-driven economy – to share data in a fair and trustworthy way – to tackle the aforementioned challenges. Therefore, Utrecht's role – and that of the national government – is largely to develop policies that other parties need to comply to.

The marketplace is open to anyone that want to use or share data, but access to the data itself is restricted. It's not open access to the data, it's open access to the catalogue; data can be used commercially and restrictions thus depend on the parties who publish their data. A user therefore enters a contract with the publisher, without Utrecht's interference in between. Utrecht also does not regulate the data quality, partly because the platform is bigger than one city. Utrecht has ongoing questions regarding the ownership of data, or whether the data platform operator would be allowed to create services with the data on the platform, and in general, how ideas regarding data standard openness will evolve in practice.

The marketplace is hosted on OpenStack, a free and open source (available on GitHub) software platform for cloud computing. This allows for easy portability in theory, although Utrecht doesn't have the necessary skills to do so in practice – and switching always comes with a cost, no matter what.

Vendor lock-in mainly occurs because there are few vendors that supply to the government market – it is an oligopoly – and they control many aspects, such as the intellectual property and data models. For the current platforms, Utrecht is using open source code and open data, and specifies in its contract that Utrecht will be the owner of data, so Utrecht is in theory capable of contracting a new party to develop a new platform similar to what is being used now. However, proper contract specification depends on knowledge of the market and on knowledge of vendor lock-in, and a vendor lock-in proof contract as such can't be guaranteed. There is a national movement, 'Common Ground', that seeks to separate the data from the applications, to be able to access data easier and more standardised, so that software can be reused across all municipalities in the Netherlands.

5.4 Glasgow

Glasgow was chosen as a case because it is a smart city part of the EU Ruggedised initiative. It was also known beforehand that Glasgow has had potentially interesting experiences with vendor lock-in. The case study was conducted by phone on the 23rd of May, 2018, with Glasgow's 'Group Manager – City Energy & H2020 Ruggedised Lead' and with Glasgow's 'Director at Derryherk Limited.

Variable	Level	Indicator
Ecosystem		
Development Approach	Bottom-up	"Our objective was to create a data hub, and we had four demonstrations, which were safety, health, energy, and transport." [2:00]
Envisioned Result	Digital Community	"Whether applications can be developed by another party, that really depends on the nature of the data […]." [10:30]
Architectural Framework	ESPRESSO	"What we are trying to do […] is to do as much as possible with Platform as a Service and in-house development, not on a code level but on a use case and management level." [39:30]
Platform		
Interoperability	High	"[…] The aspiration was to develop solutions, understandings, commonalities, and problems, […] we are as a comparison quite far ahead and reasonably successful." [44:45]
Resilience	High	"Yes." (to the question: "You would for example have kept your platform-app dependencies to a minimum, because you focus on open source things and modularity, they would be loosely coupled?") [55:00]
Application		
Data Standard Openness	High	"Absolutely." (to the question: "In general, it can be said that the data is published to agreed formats, there are certain standards of data formats?") [18:00]
API Openness	Medium	"In the future, most of the data is going to be on Azure, and we want to minimise the amount of code developed internally, so we're trying to use as much as possible off the shelf software applications." [23:15]
Architecture Openness	Low	"We do use some open source applications, but we use some proprietary applications as well." [25:00]
Documentation Transparency	Medium	"I'm absolutely sure the procurement team has had to incorporate provisions for cooperation for an exit strategy." [32:00]
Vendor Lock-In		
Current	Low	"No, we don't." (to the question "So you would say that you currently do have a vendor lock-in problem?") [36:30]
Predicted	Low	"We have investigated the vendor lock-in problem and therefore hope not to fall into that trap […] It's not going to happen." [36:30]

Table 6: Case Study Glasgow

A smart city utilises technology and data. For Glasgow, this consists of for example optimising fleet routes with smart tracking devices regarding the sector transportation. An important lesson learned

was that gathering and storing as much data as possible meant that most data had little to no value; merely having data does not help anyone, the first step is to figure out which data could be relevant to solve which problem, and then to try to find that data.
Related to this shift of thinking is how Glasgow now explicitly aspires to improve its services and the inclusiveness of its citizens. Glasgow internally encourages data sharing and externally – with other cities – the adoption of (data management) standards (working with, for example, the Scottish Cities Alliance). However, Glasgow also recognises the many factors (corporate, political, economical…) that influence what cities do, and has found it to be infeasible to wait on Scottish governmental support. Instead, Glasgow has for example procured an application on its own, and other cities – and the government – have followed Glasgow upon seeing the success of this.

Glasgow has one data hub – OpenGlasgow – which is described as a platform where many (external) sources of data can be analysed together through an automated process. This is reminiscent of for example the Lambda Architecture (Hausenblas, M. and Bijens, N., 2017), and comes across as being more advanced than simply having all data accessible through one point.
Glasgow has categorised its data; in general, it owns the more static data itself, and the more dynamic the data, the more (and different) agreements for access (or uploading) there exist. It primarily (but not exclusively) works with public organisations.
Open (and standardised) APIs can be used to access the platform. Open data can be accessed and consumed by anyone, but an account is required to access other data. An account is also required to contribute to the data, and the possibility exists to become a trusted supplier. Further, Glasgow signed up for a project involving standards regarding data quality that Glasgow's data has to meet. Mechanisms are as such in place to guarantee the quality of the data.

The platform is open source software, modified to meet the requirements of the Glasgow City Council. The current platform was built largely by Glasgow itself, but will leave a legacy system that requires internal software management. In the future, most data will be accessed through (but not stored on) Azure Stack, and Glasgow will use as many off-the-shelf applications and services as possible (for example, data transportation and mapping will be handled by an open source application). This also includes using frameworks such as Django. This will minimise the amount of bespoke code development and maximise the use of functionalities and services within the platform, so as to not leave a legacy system. This was a key lesson learned.

Internally, applications have already been developed using the data – such as a rubbish collection application – and in the future, the intent is there for external parties to be able to develop their own applications as well. However, Glasgow does not want to be dependent on external parties (commercial entities), and the precise way for external parties to be able to develop their own applications is as such an ongoing process; perhaps a second data hub – such as one developed by a university – can handle this.

Although it is not quite a vendor lock-in (because it is not a specific vendor), in order to maintain the current platform, a lot of software developers are required. This is a reason for moving to Azure Stack. Similarly, Glasgow has moved away from companies that offer entire platforms, and instead now acquires only the relevant software services, much like what BPM/SOA advises (Behara, 2006). Glasgow views the Platform as a Service approach as a way of avoiding vendor lock-in. In general, Glasgow has seen vendor lock-in problems occur in other cities, and has as a consequence anticipated how to not end up in a vendor lock-in situation.

5.5 Umeå

Umeå was chosen as a case because it is a smart city part of the EU Ruggedised initiative. The case study was conducted by phone on the 28th of May, 2018, with Umeå's 'Project Manager RUGGEDISED'.

Variable	Level	Indicator
Ecosystem		
Development Approach	Bottom-up	"Yes." (to the question: "So would you say that you work from the individual projects, solutions, you get those, and then you try to integrate them in a platform – but you don't have the platform yet?")
Envisioned Result	Digital Community	"Yes, definitely, one of the goals of collecting all the data in one place is for citizens, and also for companies, to develop their own product from it."
Architectural Framework	ESPRESSO	"Yes." (to the question: "You work with ESPRESSO, right?")
Platform		
Interoperability	Medium (High)	"When it comes to standards we have the partner RISE within Ruggedised […] They are working for all cities in Ruggedised, they are looking to find standards that everyone could use."
Resilience	Medium (Low)	"Of course we know that we are not going to store everything here, there has to be some kind of connection."
Application		
Data Standard Openness	Medium (High)	"Yes." (to the question: "So the data that exists is not published to agreed formats and the same open standards and such, but you want to move to that eventually.")
API Openness	Medium (Low)	"No, I don't think we have come so far […] We need some kind of case before we can discuss this properly […] But the general idea is that everything should be open." (to the question: "Could the data be owned by the provider of the API instead of the use, do you foresee any potential conflict, have you thought of that?")
Architecture Openness	Low	"I don't think we have come so far that we could know, even if I would know." (to the question: "The applications that will be used, can they be developed by other applications?")
Documentation Transparency	Medium (Low)	"Yes." (to the question: "You would try to account for that when selecting your suppliers or applications, like documenting an exit strategy?")
Vendor Lock-In		
Current	Low	"We only heard about other experiences, so we don't."
Predicted	Low[5]	"We are not sure what is done and what is not done."

Table 7: Case Study Umeå

[5] Suspected, but unknown, as there is currently no person that is aware of any potential measures taken against vendor lock-in.

A smart city is part of working towards a sustainable city. Umeå is a growing city, as is its goal – it is the largest city in northern Sweden, and the Innovation District is the largest workplace in northern Sweden – but this growth should be done in a sustainable and transparent way. Communication with citizens is important; to explain why certain construction projects are undertaken (for sustainable growth, not so much for profit) or to show the largely 'invisible' smart city projects. Umeå does not have a specific smart city strategy as such, but it has participated in initiatives such as EU Ruggedised before.

Umeå has a clear vision of what its smart city platform (or, its open data platform) should be, but it isn't there yet. For now, data is spread out over various platforms, in various formats, and can be hard to find and prone to be misunderstood. Therefore, Umeå is trying to visualise its data in one map or picture. The platform Umeå is currently considering, OpenDataSoft, supports this visualisation, unlike other options that have been considered, and is further being considered based on its attitude towards standardisation. However, Umeå itself won't define the exact (open) standards; RISE (Research Institutes of Sweden, a participant in EU Ruggedised) has this task within the guidelines set by Umeå.
Not all data accessible through the platform will be open data, out of for example privacy concerns, as Umeå works together with many semi-public companies such as the utilities, and energy data is considered to be the property of the citizen in question. The platform will therefore have an open part and a closed part, as well as a 'fun' part, where miscellaneous (and possibly uncleansed) data will be stored, for example the output of various IoT devices. All of this will work on open standards.
Umeå would like to cooperate closer with other cities, that at the moment use different standards, formats, and definitions, but this is very much a work in progress. Umeå has procured some systems together, has done some IT projects together, and intends to use the platform together, but so far only with the closest cities.
Umeå intends for citizens or companies to be able to use the data to develop a new application or service, but this will most likely not be for commercial purposes; it would be put on the platform free for everyone.

Umeå has no experience with vendor lock-in, but has been warned about it and is aware of the 'threat'. However, because of private reasons, there is currently no person that is aware of any potential measures taken against vendor lock-in. Similarly – and also because it is unknown what the eventual smart city platform will be – there is very little knowledge about themes related to portability and architecture, or the APIs in general.

Umeå is an interesting case, for it is the one with the least knowledge about vendor lock-in. Amersfoort, which is in a similarly exploratory phase as Umeå is, indicates to have some awareness as to how to prevent a vendor lock-in (an exit strategy regarding gaining access to file formats and ownership of data, ensuring portability, instead of simply switching suppliers), but Umeå seems to have less awareness. This might be because of the aforementioned private reasons, but for the moment, no one seems to know much about vendor lock-in.

5.6 Cross-Case Analysis

In this paragraph, the cross-case analysis is discussed. The within-case analyses are compared to find patterns that support or reject the formulated propositions. Propositions are supported when more than half (i.e. three or more) cases support the proposition without taking scores of 'Medium' into account. This comparison happens in Table 8: 'Cross-Case Analysis', and in the subsequent reflections upon the individual propositions and the case studies in general. Based on this, a revised conceptual model is presented.

Below the cross-case analysis. Propositions 1a, 1b, and 1c are excluded, as no single case can support or reject these sub-propositions on its own:

Variables	**Rotterdam**	**Amersfoort**	**Utrecht**	**Glasgow**	**Umeå**
Development Approach	Top-down	Top-down	Bottom-up	Bottom-up	Bottom-up
Envisioned Result	Digital Community	Digital Community	Data Market	Digital Community	Digital Community
Architectural Framework	ESPRESSO	FIWARE	FIWARE	ESPRESSO	ESPRESSO
Platform Interoperability	High	High	High	High	High(Medium)
Platform Resilience	High(Medium)	Medium	High	High	Low(Medium)
Data Standard Openness	High	High	High(Medium)	High	High(Medium)
API Openness	Medium	Medium	Medium	Medium	Low(Medium)
Architecture Openness	Low	Medium	High(Medium)	Low	Low
Documentation Transparency	Low	High	High(Medium)	High(Medium)	Low(Medium)
Current Vendor Lock-In	High	High	High	Low	Low
Predicted Vendor Lock-In	Low	Low	Low	Low	Low[6]
Propositions					
Proposition 2a	Yes	Yes	Yes	Yes	Yes
Proposition 2b	No	No	No	No	No
Proposition 2c	No	No	Yes	No	No
Proposition 2d	No	Yes	Yes	Yes	No
Proposition 3a	Yes	Yes	Yes	Yes	Yes
Proposition 3b	No	No	No	No	No
Proposition 3c	No	No	Yes	No	No
Proposition 4a	No	No	No	No	No
Proposition 4b	No	No	Yes	No	No
Proposition 4c	No	No	Yes	Yes	No

Table 8: Cross-Case Analysis

All cases uphold propositions 2a and 3a, and a majority of cases uphold proposition 2d.

[6] Suspected, but unknown, as there is currently no person that is aware of any potential measures taken against vendor lock-in.

Below, the individual propositions will be reflected upon. Sub-propositions 1a, 1b, and 1c will be analysed separately, because of their diverse nature, while the other sub-propositions (e.g. 2a, 2b, 2c, and 2d) will be analysed as one proposition (e.g. proposition 2).

Proposition 1a

A 'top-down' development approach positively moderates the relationship between Platform Interoperability and Application Openness.

This proposition is tested by comparing the score of 'Platform Interoperability' ('High' for every case) with the sum of the scores of the four variables of 'Application Openness' ('Data Standard Openness', 'API Openness', 'Architecture Openness', and 'Documentation Transparency'), where 'High' counts as 3, 'Medium' as 2, and 'Low' as 1.

Rotterdam and Amersfoort have a top-down development approach, and score 7 and 10.
Utrecht, Glasgow, and Umeå have a bottom-up development approach, and score 11, 9, and 6.
17 (7+10) divided by 2 (two cases) is 8.5, while 26 (11+9+6) divided by 3 (three cases) is 8.67.

These numbers are very similar. Further, the two cases with the top-down development approach score the second highest (10) and second lowest (7). Based on these numbers, the proposed moderating relationship has not been found to exist.

Intuitively speaking, a top-down development approach ensures that there is standardisation beforehand; a platform would be defined with various standards, and any subsequent projects would adhere to these standards.
However, a platform is not the only 'trigger' that can cause this kind of standardisation. Amersfoort cooperates closely with a variety of parties (including the Economic Board of Utrecht), and Amersfoort has the second highest score (with Utrecht having the highest). Glasgow, the third highest score, has more experience than the other cases when it comes to vendor lock-in, and is in the process of moving to another platform. Umeå, the lowest score, has the least experience (or, awareness), and is also still 'looking around' to try to cooperate with other parties; only a few directly neighbouring cities have expressed interest.

In conclusion, proposition 1a is rejected.
It is hypothesised that cooperation with others (in the context of smart city platforms and standardisation) does have the moderating relationship of this proposition.
This does not necessarily mean that a top-down development approach does not have this kind of moderating relationship either, but if it does, then it is alongside other factors.

Proposition 1b

A 'digital community' ideal outcome positively moderates the relationship between Platform Interoperability and Application Openness.

This proposition is tested by comparing the score of 'Platform Interoperability' ('High' for every case) with the sum of the scores of the four variables of 'Application Openness' ('Data Standard Openness', 'API Openness', 'Architecture Openness', and 'Documentation Transparency'), where 'High' counts as 3, 'Medium' as 2, and 'Low' as 1.

Rotterdam, Amersfoort, Glasgow, and Umeå, have a digital community outcome, and score 7, 10, 9, and 6.
Utrecht has a data market ideal outcome, and scores 11.

32 (7+10+9+6) divided by 4 (four cases) is 8, while the sole data market case scores 11.

Based on these numbers, the proposed moderating relationship has not been found to exist. Instead, the opposite (a 'data market' ideal outcome positively moderates the relationship between Platform Interoperability and Application Openness) seems likelier.
However, the fact that there is only one case with a data market ideal outcome, is problematic. It could be that this case is an outlier.

Intuitively speaking, a digital community ideal outcome ensures that there is more attention paid towards the standardisation, openness, and documentation, of the application factors; supporting such a community requires more work and carries more risk than supporting only a data market.
Curiously enough, the case with the most developed vision of a digital community (Rotterdam) has the second lowest score.
The highest three scores (Utrecht, Amersfoort, and Glasgow), all score 'High' for 'Documentation Transparency', which sets them apart from the other cases. However, 'Documentation Transparency' concerns the documentation regarding vendors, not regarding the specifications for such a hypothetical community.

In conclusion, proposition 1b is rejected.
It is possible that the inverse proposition would be supported; a 'data market' ideal outcome positively moderates the relationship between Platform Interoperability and Application Openness. However, this requires more cases with a 'data market' as ideal outcome.
It seems unlikely that there is a correlation with 'Documentation Transparency', but the variable 'Documentation Transparency' could be split up in various factors to test this.

Proposition 1c

The choice of architectural framework has an impact on the relationship between Platform Interoperability and Application Openness.

This proposition is tested by comparing the score of 'Platform Interoperability' ('High' for every case) with the sum of the scores of the four variables of 'Application Openness' ('Data Standard Openness', 'API Openness', 'Architecture Openness', and 'Documentation Transparency'), where 'High' counts as 3, 'Medium' as 2, and 'Low' as 1.

Rotterdam, Glasgow, and Umeå, follow the ESPRESSO framework, and score 7, 9, and 6.
Amersfoort and Utrecht follow the FIWARE framework, and score 10 and 11.
22 (7+9+6) divided by 3 (three cases) is 7.33, while 21 (10+11) divided by 2 (two cases) is 10.5.

These numbers indicate that the FIWARE framework positively moderates the relationship between 'Platform Interoperability' and 'Application Openness'. Further, the two cases following the FIWARE framework have the two highest scores.

Per Appendix I.II: 'Architectural Frameworks', FIWARE is more focused on the technical side, while ESPRESSO takes a broader, more strategical perspective. As such, this result makes sense, because the 'more technical side' translates well to 'Application Openness'.
It would be interesting to test whether the ESPRESSO framework has a similar effect on platform governance, but this falls outside the scope of this thesis.
Finally, this should not be seen as a dichotomous comparison, as for example Utrecht intends (this is a work in progress) to use ESPRESSO and FIWARE in combination with each other.

In conclusion, proposition 1c is supported.
However, there have been no cases with a ‘Low’ score for ‘Platform Interoperability’, and there have been no cases that use neither the ESPRESSO framework nor the FIWARE framework. Both of these need to be accounted for in order to fully accept proposition 1c.

Proposition 2

A higher level of Application Openness leads to a lower level of Predicted Vendor Lock-In.

Every case scores ‘Low’ for ‘Predicted Vendor Lock-In’, although this is uncertain for Umeå.

‘Application Openness’ is split up in ‘Data Standard Openness’, ‘API Openness’, ‘Architecture Openness’, and ‘Documentation Transparency’.

Every case scores ‘High’ for ‘Data Standard Openness’, although this is rounded up from ‘Medium’ for both Utrecht and Umeå.
As such, proposition 2a is supported by all cases.

Rotterdam, Amersfoort, Utrecht, and Glasow, score ‘Medium’ for ‘API Openness’.
Umeå scores ‘Low’ for ‘API Openness’, although this is rounded down from ‘Medium’.
As such, proposition 2b is rejected by all cases.

Rotterdam, Glasgow, and Umeå, score ‘Low’ for ‘Architecture Openness’.
Amersfoort scores ‘Medium’ for ‘Architecture Openness’.
Utrecht scores ‘High’ for ‘Architecture Openness’, although this is rounded up from ‘Medium’.
As such, proposition 2c is rejected by the majority (four) of cases.

Rotterdam and Umeå score ‘Low’ for ‘Documentation Transparency, although this is rounded down from ‘Medium’ for Umeå.
Amersfoort, Utrecht, and Glasgow, score ‘High’ for ‘Documentation Transparency’, although this is rounded up from ‘Medium’ for both Utrecht and Glasgow.
As such, proposition 2d is supported by a majority (three) of cases.

A higher level of ‘Data Standard Openness’ and ‘Documentation Transparency’ thus lead to a lower level of ‘Predicted Vendor Lock-In’.
Intuitively speaking, these two variables cover aspects that are worked on relatively early in the development of a smart city platform.
ESPRESSO explicitly focuses on ‘Data Standard Openness’, and Rotterdam and Glasgow (both following the ESPRESSO framework) have the highest amount of ‘High’ scores (10) concerning ‘Data Standard Openness’. Umeå, which also follows the ESPRESSO framework, has a lower score. This might be explained by Umeå still being in an exploratory phase, but Amersfoort (following the FIWARE framework but also being in an exploratory phase) has a higher score. Utrecht, following the FIWARE framework but being in a more mature development phase, has the lowest score. There doesn’t seem to be a conclusive relationship between the architectural framework (or maturity) and ‘Data Standard Openness’, especially given the conclusion drawn from proposition 1c.
Amersfoort and Umeå indicate not yet knowing much about ‘API Openness’ and ‘Architecture Openness’, because they are still in an exploratory phase.
Purely looking at the numerical summary of Table 2: ‘Case Study Overview’, regarding ‘API Openness’, Amersfoort and Utrecht have the highest amount of ‘High’ scores and the lowest amount of ‘Medium’ and ‘Low’ scores. This reinforces proposition 1c.

Amersfoort's 'Medium' score for 'Architecture Openness' is explained by its focus on cooperation with other cities, which would necessitate portability, which is part of 'Architecture Openness'. Utrecht's 'High' score could be similarly explained, but is more likely to be the result of Utrecht having given the most thought to the 'deeper' technical aspects of smart city platforms.
Regarding 'Documentation Transparency', Amersfoort's score of 'High' is explained by its focus on cooperation, while Glasgow's score of 'High' is explained by its awareness of vendor lock-in happening to other cities. As posited before, 'Documentation Transparency' could be split up in multiple variables. In the original conceptual model, it captures the documentation of applications and services (e.g. requirements, extensibility) and of tenders (e.g. exit strategies). There is a difference between these two, as a case's awareness of vendor lock-in (e.g. how does a vendor lock-in happen, what can be done to prevent it) and a case's cooperation with other cities (e.g. for procurement or standardisation, as hypothesised during the discussion of proposition 1a) both influence the tendering process. This can be captured by a variable 'Contractual Obligations'.

Regarding 'Predicted Vendor Lock-In', the conceptual model is based on (an experience or awareness of) 'Current Vendor Lock-In' influencing the smart city platform development. Therefore, although every case scores 'Predicted Vendor Lock-In' as 'Low', three categories can be made herein:

1. Rotterdam, Amersfoort, and Utrecht, have a 'Current Vendor Lock-In' of 'High' leading to a 'Predicted Vendor Lock-In' of 'Low'. They are currently experiencing a vendor lock-in, and are explicitly designing their smart city platform in such a way so as to get out of these vendor lock-ins.
2. Glasgow has a 'Current Vendor Lock-In' of 'Low' leading to a 'Predicted Vendor Lock-In' of 'Low'. Glasgow has no (or, not a lot of) personal experience with vendor lock-in, but is intimately aware of other environments where a vendor lock-in has occurred. Glasgow is applying these lessons to its own smart city platform in order to prevent a possible future vendor lock-in.
3. Umeå has a 'Current Vendor Lock-In' of 'Low' leading to a 'Predicted Vendor Lock-In' of 'Low'. Umeå is far less aware of how to prevent a vendor lock-in than Glasgow is, and is further in an earlier development phase than Glasgow is.

It is hypothesised that classifying cases along these three strategies is a good indicator for the eventual outcome of the platform development process. When looking at 'Platform Interoperability', Rotterdam, Amersfoort, and Utrecht, have the highest amount of 'High' scores (10, 11, and 9), closely followed by Glasgow (8), with Umeå having markedly fewer 'High' scores (4).

In conclusion, propositions 2a and 2d are supported.
It is hypothesised that proposition 2 as a whole would be supported, given cases with more mature platforms. The maturity level of a smart city platform, analysed through for example the Smart City Strategic Growth Map (ESPRESSO, 2016) or the evolutionary framework of Tiwana, A. (2014), should therefore be taken into account.
'Documentation Transparency' currently seems to include what literature refers to as 'Contractual Obligations', and should as such be split up.

Proposition 3

A higher level of Platform Interoperability leads to a higher level of Application Openness.

Every case scores 'High' for 'Platform Interoperability', although this is rounded up from 'Medium' for Umeå.

'Application Openness' is split up in 'Data Standard Openness', 'API Openness', and 'Architecture Openness'.

Every case scores 'High' for 'Data Standard Openness', although this is rounded up from 'Medium' for both Utrecht and Umeå.
As such, proposition 3a is supported by all cases.

Rotterdam, Amersfoort, Utrecht, and Glasow, score 'Medium' for 'API Openness'.
Umeå scores 'Low' for 'API Openness', although this is rounded down from 'Medium'.
As such, proposition 3b is rejected by all cases.

Rotterdam, Glasgow, and Umeå, score 'Low' for 'Architecture Openness'.
Amersfoort scores 'Medium' for 'Architecture Openness'.
Utrecht scores 'High' for 'Architecture Openness', although this is rounded up from 'Medium'.
As such, proposition 3c is rejected by the majority (four) of cases.

As noted before, there are no cases with a 'Low' score for 'Platform Interoperability'.
Interestingly, the sub-propositions of proposition 3 align with the equivalent sub-propositions of proposition 2 (i.e. propositions 2c and 3c are both supported by Utrecht, but rejected by the other cases). This is because there are also no cases with a 'Low' score for 'Data Standard Openness'.
The two variables do not necessarily measure the same. For instance, although Umeå's 'High' was rounded up from 'Medium' for both, Utrecht scored an unrounded 'High' for 'Platform Interoperability' and a 'High' rounded up from 'Medium' for 'Data Standard Openness'.
Further, ESPRESSO explicitly views the 'Data Lake' layer (see Figure 3: 'Hamburger Model' as part of ESPRESSO in Appendix I.II: 'Architectural Frameworks') as the place to foster interoperability. Therefore, the cases following the ESPRESSO framework (Rotterdam, Glasgow, and Umeå) can be expected to have a similar score for both 'Platform Interoperability' and 'Data Standard Openness'.
However, the fact that this is true for all other cases as well, justifies ESPRESSO's approach of viewing 'Data Standard Openness' as a key to 'Platform Interoperability'. This is contrary to literature, which focuses on 'API Openness'.

The discussion on the development phases – the maturity level – of smart city platforms, as part of proposition 2, applies to proposition 3 as well.

In conclusion, proposition 3a is supported.
It is (as with proposition 2) hypothesised that proposition 3 as a whole would be supported, given cases with more mature platforms.

Proposition 4

A higher level of Platform Resilience leads to a higher level of Application Openness.

Rotterdam, Utrecht, and Glasgow, score 'High' for 'Platform Resilience', although this is rounded up from 'Medium' for Rotterdam.
Amersfoort scores 'Medium' for 'Platform Resilience'.
Umeå scores 'Low' for 'Platform Resilience', although this is rounded down from 'Medium'.

'Application Openness' is split up in 'API Openness', 'Architecture Openness', and 'Documentation Transparency'.

Rotterdam, Amersfoort, Utrecht, and Glasow, score 'Medium' for 'API Openness'.
Umeå scores 'Low' for 'API Openness', although this is rounded down from 'Medium'.
As such, proposition 4a is rejected by all cases.

Rotterdam, Glasgow, and Umeå, score ‘Low’ for ‘Architecture Openness’.
Amersfoort scores ‘Medium’ for ‘Architecture Openness’.
Utrecht scores ‘High’ for ‘Architecture Openness’, although this is rounded up from ‘Medium’.
As such, proposition 4b is rejected by the majority (four) of cases.

Rotterdam and Umeå score ‘Low’ for ‘Documentation Transparency, although this is rounded down from ‘Medium’ for Umeå.
Amersfoort, Utrecht, and Glasgow, score ‘High’ for ‘Documentation Transparency’, although this is rounded up from ‘Medium’ for both Utrecht and Glasgow.
As such, proposition 4c is rejected by a majority (three) of cases.

‘Platform Resilience’ was treated as the technical side of resilience, as it was by Tiwana, A. (2014) and especially by the Cyber Physical Systems Public Working Group (2017).
However, Rotterdam concerns itself with the social side of resilience, noting that a smart city should also be there for those not experienced with modern IT developments. Similarly, Amersfoort highly values citizen participation and co-creation, and concerns itself with the role of the municipality when it comes to privacy (and governance in general).
Tiwana, A. (2014) did include ‘platform-governance alignment’ as part of his definition of resilience, which is why Rotterdam’s score of ‘Medium’ for ‘Platform Resilience’ was rounded up to ‘High’, and why Amersfoort has a score of ‘Medium’ instead of ‘Low’.
Overall, however, the social side of resilience – or, platform-governance alignment – was underrepresented in the case studies that were carried out. All cases, with the exception of Utrecht, noted something about this; Glasgow noted that it seeks to increase the inclusiveness of its citizens, while Umeå noted that it seeks to be more transparent towards its citizens.
Interestingly, Rotterdam and Amersfoort – the cases most concerned with platform-governance alignment – are also the two cases with a top-down development approach, which aligns with Dameri (2013): “The showed bottom-up development path often neglects two main aspects: the smart city governance and the citizens.”
It is uncertain whether platform-governance alignment has a direct influence on vendor lock-in, but it certainly has an influence on the platform development process (which in turn leads to a certain level of vendor lock-in).
Therefore, it is proposed to expand ‘Platform Resilience’ into a full-fledged ‘Platform Governance’ category.

The discussion on the maturity level of smart city platforms applies here as well; (the technical side of) ‘Platform Resilience’ is largely something visible in practice. It therefore makes sense that Rotterdam, Utrecht, and Glasgow have a score of ‘High’; these are precisely the three cases that are beyond the exploratory phase of Amersfoort and Umeå.
Similarly, propositions 4a and 4b (concerning ‘API Openness’ and ‘Architecture Openness’) are overwhelmingly rejected, while proposition 4c (concerning ‘Documentation Transparency’) is only narrowly rejected.

In conclusion, proposition 4 as a whole is rejected.
It is (as with proposition 2) hypothesised that proposition 4 as a whole would be supported, given cases with more mature platforms.
‘Platform Resilience’ should be split up between a more technical side and a more social side, the latter expanding to include factors pertaining to ‘Platform Governance’. It is unknown what ‘Platform Governance’ would exactly consist of, and what it would affect, given that this is a large field of research. It is beyond the scope of this thesis to determine suitable variables and relationships, but a

suggested first step would be to consult the chapter 'Platform Governance' of Tiwana, A. (2014: 118-151).

Reflection

Beyond the reflections upon the individual propositions, there are some general reflections to be made upon the cases.

The difference between Rotterdam and Utrecht is of particular interest, as they cooperate closely within the setting of this thesis.
One reason may be that Rotterdam is praised (e.g. Appendix II: Interviews, VI) for its attitude, perhaps best summed up as 'fail fast, learn fast'. Rotterdam does things, sees what happens, and learns from this. This is the approach Rotterdam explicitly takes regarding 'Documentation Transparency'. Looking at the numerical summary of Table 2: 'Case Study Overview', this might explain Rotterdam's large amount of 'Low' scores as well (15, with the second and third largest amount being 6). These numbers do not indicate that Rotterdam is performing badly, as Rotterdam has the median amount of 'High' scores (26) and is above the mean (24.4).
Another reason may be the subjective nature of a case study; the case study with Utrecht dove deeper into the technical details (which largely relate to 'Application Openness') and the storytelling was more concise. As such, there were more examples of what is happening and what is being considered, while it is unknown if Rotterdam has put the same kind of thought and effort into some of these aspects ('unknown unknowns').

Amersfoort has the highest amount of 'High' scores (29) and the lowest amount of 'Low' scores (3), per Table 2: 'Case Study Overview'. This is surprising, as Amersfoort is still in an exploratory phase and is not even sure whether it will keep using the FIWARE platform. A key feature of Amersfoort is its focus on cooperation (and on citizen participation and co-creation), and it might be that Amersfoort has learned a lot from cities such as Utrecht, Amsterdam, or Eindhoven, which are all further along in the development of their smart cities than Amersfoort is.
Interestingly, for a case still in an exploratory phase, Amersfoort showed remarkable insight with regards to how to prevent vendor lock-in (as backed up by its score of 'High' for 'Documentation Transparency'). This might also be because of its focus on cooperation.

Utrecht upholds many propositions, and is the only case that is ranked as 'High' concerning 'Architecture Openness'. However, Table 2: 'Case Study Overview' shows that Utrecht has the second lowest amount of 'High' scores (24). On the other hand, it also has the second lowest amount of 'Low' scores (5), and it has the median 'Medium' score (6).
This oddity is explained by the fact that three of Utrecht's 'Application Openness' variables have been rounded up from 'Medium' to 'High'. Although such a rounding helps with the case analyses, some nuance might have been lost.

Glasgow is an interesting case to follow, as it is going to migrate to Microsoft Azure Stack. This is interesting, because Microsoft Azure is a cloud service used as a case in literature pertaining to vendor lock-in. On the other hand, there is also literature on for example the semantic representation of Microsoft Azure's APIs, to further standardisation (e.g. Martino et al., 2014). Glasgow has so far managed to not experience vendor lock-in problems, by watching what happened to other cities and taking proactive measures. If Glasgow maintains its cautious and proactive approach, this migration could be successful.
This choice of migration was made in order to minimise bespoke code, and as part of this, Glasgow will also use frameworks such as Django, something that negatively impacts 'Architecture Openness'.

Glasgow has indicated that it will use as many off-the-shelf applications and services as possible, using open source applications.
All in all, Glasgow's Platform as a Service approach is very interesting to follow.

Umeå is the case with the lowest amount of 'High' scores (16) and the highest amount of 'Medium' scores (13). Umeå, like Glasgow, also has a 'Low' for 'Current Vendor Lock-In', but Umeå is not very certain regarding the topic of vendor lock-in (both current and predicted). All of this could be explained by the private reasons mentioned in paragraph 5.5 'Umeå', but given that Umeå is in an exploratory phase similar to Amersfoort, this does paint a worrisome picture.

With this, an answer is given to sub-question five: "How do the smart city platform architectural factors influence vendor lock-in?". This will be incorporated in the revised conceptual model of the next paragraph.

5.7 Revised Conceptual Model

Based on the findings discussed in the previous paragraph, a revised conceptual model is proposed. Compared to the conceptual model of chapter 3. 'Conceptual Model', it takes the following points into account:

- 'Ideal Outcome' has been removed from 'Platform Ecosystem', per the rejection of proposition 1b. For clarity, 'Platform Ecosystem' has been fully written out in the below revised conceptual model.
- 'Documentation Transparency' has an important effect on vendor lock-in, but should be split up (as hypothesised during the discussion of propositions 1a, 1b, and 2) into:
    - 'Documentation Transparency', which covers the documenting of e.g. requirements and extensibilities of applications and services.
    - 'Contractual Obligations', which covers the documenting of exit strategies pertaining to vendors, e.g. whether data be maintained in usable format upon switching. This could also cover degrees of 'awareness of vendor lock-in' and 'coordination with other smart cities'. Per Tiwana, A. (2014: 135) and Boudreau (2010), this is part of 'Platform Governance'. Similarly, Rustenburg (2017) includes 'Relational Control' as part of 'Platform Governance'. However, the exact relationship will need to be investigated, hence the grey dashed line.
- 'Maturity', which covers the development phase of the smart city platform (hypothesised during the discussion of propositions 2, 3, and 4).
- 'Platform Governance', which covers the social side of 'Platform Resilience' (hypothesised during the discussion of proposition 4). The exact variables will need to be investigated, hence the grey dashed line (and hence why 'Resilience' remains unchanged).
    - However, from the analysed literature (e.g. Dameri, 2013; Mulligan and Olsson, 2013), the following proposition can already be made:
      "A 'top-down' development approach positively moderates the relationship between Platform Governance and Application Openness."

None of the other variables and proposed relationships from the original conceptual model have been removed, despite for example 'API Openness' not having found to have any relationship or impact. However, this is suspected to be a consequence of smart city platforms not being sufficiently mature yet, and further research is required to justify a variable's exclusion from the conceptual model.

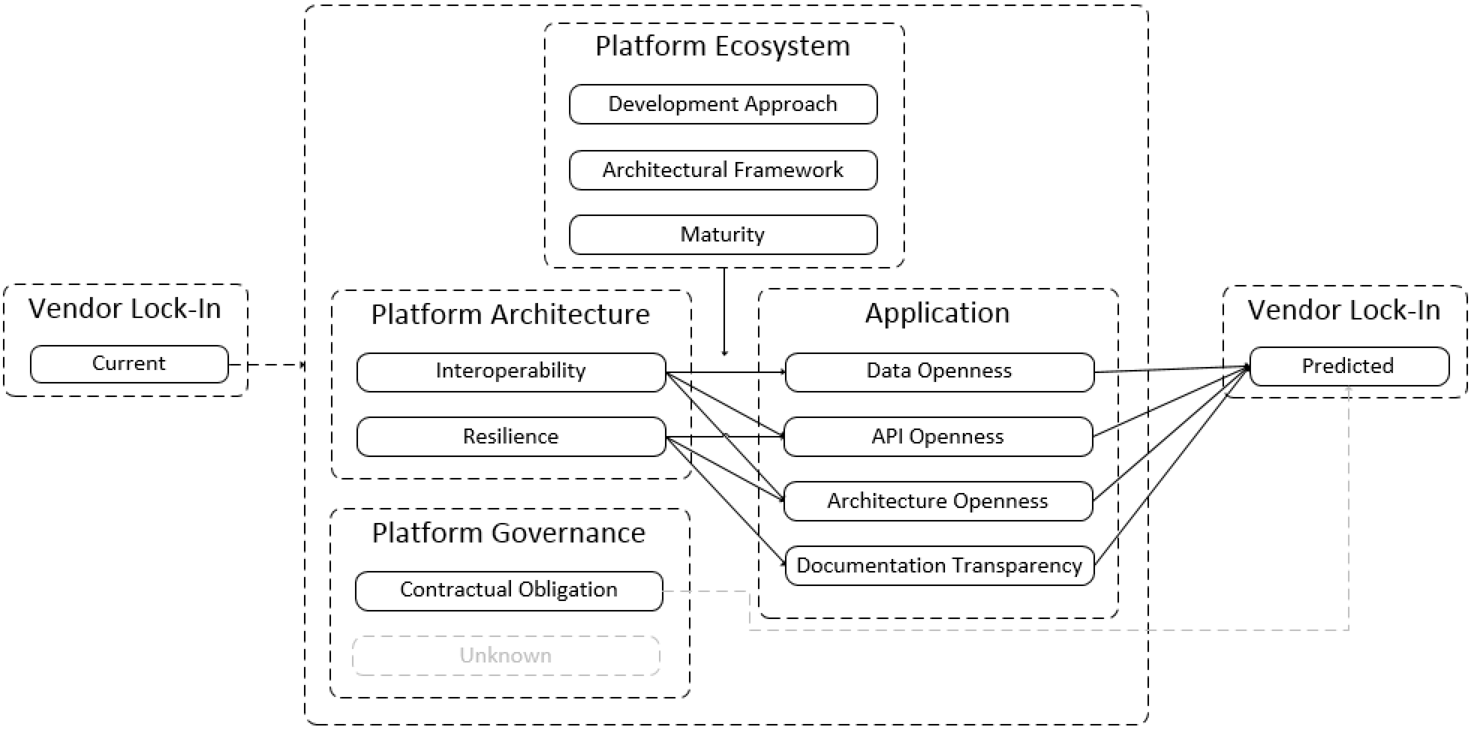

Figure 2: Revised Conceptual Model

6. Conclusion

This thesis has explored a conceptual model concerning the characteristics of and the relationship between interoperability and vendor lock-in by answering the research question: "How do smart city platform architectural factors contribute to vendor lock-in of smart city platform owners?
Five cases of smart city platforms have been analysed, resulting in the conclusions below; general conclusions, academical contributions, and practical implications and recommendations. These are subject to limitations, which are discussed afterwards, after which proposals for future research are given.

6.1 Conclusions

From the proposed conceptual model, the following propositions have been supported:

- **Proposition 1c: The choice of architectural framework has an impact on the relationship between Platform Interoperability and Application Openness.**
- **Proposition 2a: A higher level of Application Openness concerning Data Standard Openness leads to a lower level of Predicted Vendor Lock-In.**
- **Proposition 2d: A higher level of Application Openness concerning Documentation Transparency leads to a lower level of Predicted Vendor Lock-In.**
- **Proposition 3a: A higher level of Platform Interoperability leads to a higher level of Application Openness concerning Data Standard Openness.**

A set of additional findings are drawn from the cross-case analysis:

1. 'Documentation Transparency' has an important effect on vendor lock-in. It was initially conceptualised as a broad set of factors related to policy and documentation, but is split into more specified variables in the revised conceptual model:
    a. 'Documentation Transparency', which covers the documenting of e.g. requirements and extensibilities of applications and services.
    b. 'Contractual Obligations', which covers the documenting of exit strategies pertaining to vendors, e.g. whether data be maintained in usable format upon switching. 'Contractual Obligations' could also cover degrees of 'awareness of vendor lock-in' and 'coordination with other smart cities'. Both of these are important factors to include.
2. 'Maturity', which covers the development phase of the smart city platform, is an important variable to include. It could be measured by using the Smart City Strategic Growth Map (ESPRESSO, 2016), or by using the evolutionary framework of Tiwana, A. (2014). It is hypothesised that less mature platforms will have a lower score for, for example, 'Architecture Openness'.
3. 'Platform Governance', which covers the social side of 'Platform Resilience', is an important variable to include. This 'social side' – or, platform-governance alignment – is more important than first indicated. It is hypothesised that both a 'top-down' development approach and the ESPRESSO architectural framework positively moderate a hypothetical relationship between 'Platform Governance' and 'Application Openness'.

In general, this thesis's academic relevance lies in the contribution to literature on (standardisation of) multi-sided platforms. This thesis bridged two fields of literature – platform ecosystems and cloud-based systems – to analyse vendor lock-in in the context of smart city platforms.
The literature on generic platform ecosystems takes a largely technical view, noting that the development process happens within the constraints of a platform's governance. However, the literature specifically on smart city platforms posits that the human element and the social context (e.g. privacy concerns) are important.

This thesis's results align more with this second view; governance is not so much a constraint as it is an active steering force. It is important to consider in general, but also with regards to interoperability and the prevention of vendor lock-in. It is further hypothesised that a 'top-down' development approach positively moderates the relationship between 'Platform Governance' and 'Application Openness'.
The literature on cloud-based systems discussed vendor lock-in in situations most similar to smart city platforms; it aligned with the common characteristics of open smart city platforms and IoT platforms in general. This literature overwhelmingly suggests 'API Openness' to be the most important variable in preventing vendor lock-in.
However, this thesis suggests 'Data Standard Openness' to be the most important variable. This might be a difference between generic cloud-based systems or IoT platforms on one hand, and smart city platforms on the other.

In specific, this thesis's academic relevance consists of the analysis of certain models for and implementations of smart city architectures, such as ESPRESSO and FIWARE.
Conclusions drawn from this hold direct business relevance for smart city platform owners:
ESPRESSO is justified in viewing the 'Data Lake' layer (see Figure 3: 'Hamburger Model' as part of ESPRESSO in Appendix I.II: 'Architectural Frameworks') as the key place to foster interoperability through its PPI- and MIM-based approach. ESPRESSO views 'Data Standard Openness' as a crucial part of encouraging 'Platform Interoperability' and to preventing vendor lock-in, which is validated by this thesis's conceptual model.
FIWARE positively moderates the relationship between 'Platform Interoperability' and 'Application Openness' in general. Perhaps this is because of FIWARE's comparative focus on the technical side.
In comparison, ESPRESSO takes a broader, more strategical perspective. It is therefore hypothesised that following the ESPRESSO framework positively influences a platform's governance.
In general, cooperation between the two is encouraged.

Further business relevance consists of gaining insight into the development approaches of the various smart cities (e.g. through the case studies or the distributed questionnaire). EU Ruggedised and similar initiatives have it as their explicit goal to learn from other smart cities, and the first step towards this is becoming more familiar with what other smart cities are doing and their reasons for it. Closer cooperation is therefore encouraged on a variety of aspects:
Many cities currently use 'silo solutions' or 'point solutions', that for example use and generate data that can't be moved or used outside of this specific smart city context. Cross-city interoperability is therefore hindered. Initiatives such as the 'Dutch Smart City Strategy' of the VNG ('Vereniging van Nederlandse Gemeenten'; 'Association of Dutch Municipalities') and the procurement specifications of the GIBIT (Gemeentelijke Inkoopvoorwaarden Bij IT; 'Municipal Acquisition Prerequisites for IT') are good first steps towards cross-city interoperability.
Smart cities work on a variety of similar projects with many commonalities, such as smart lamp posts, heat maps, or the usage of traffic data. It would be sensible to develop or procure these functionalities together. A novel approach would be to cooperate on a European scale with regards to procurement, with many smart cities trying to procure the same functionalities at once, reaching a critical mass and driving prices down. However, this requires far more intimate cooperation between smart cities than currently exists. The various EU initiatives should drive this cooperation, both within (e.g. Rotterdam, Glasgow, and Umeå, as part of EU Ruggedised) and between (e.g. between the smart cities within EU Ruggedised and those within IRIS) themselves.
One way of increasing cooperation would be to use the same architectural frameworks, such as ESPRESSO or FIWARE. As noted before, these should not be seen as a dichotomous choice. ESPRESSO and FIWARE can be used in combination with each other; the former for a broader, more strategic overview, the latter for a narrower, more technical specification. In specific, the ESPRESSO strategy

of a use-case-based approach is praised, and ties in with how Rotterdam is praised for its willingness to learn from criticism and failures.
Related to this are Standard Development Organisations (SDOs). They develop standards for various industries, they cooperate with various smart cities, and they also cooperate with(in) ESPRESSO and FIWARE. However, as there are too many initiatives to be aware of all of them (and, as such, to align them), teams within SDOs can inadvertently become their own ‘silo’ and unintentionally create vendor lock-in scenario. This is a recently discovered problem, and serves to highlight the importance of cooperation.

6.2 Limitations

This thesis is subject to several limitations, which may impact the validity and reliability of the results.

A variety of problems were identified in chapter 4. 'Research Methodology', not all of which have been properly accounted for. To wit:

- The (analytic) generalisation of the case studies' result is hampered by the fact that only a limited amount of cases have been studied.
- Not all of the cases have been studied from multiple perspectives – with multiple people being interviewed per case – making the results prone to the subjective bias of the interviewee.
- Not all of the interviews have been conducted in a physical meeting.
- The investigator's ability to conduct a good case study may be lacking, and the limited number of cases studied further increases the influence of the subjective bias of the investigator.

In addition to this, it might be that a smart city further along in its development process, has more awareness of where it is lacking. A smart city that has never encountered a certain problem, may not be aware of the possibility of encountering such a problem, and may thus present a more positive view. Whereas the smart city that has encountered this problem might present a more negative view, but would in reality have learned from this and be better prepared than the unaware smart city. This can be accounted for with the proposed ‘Maturity’ variable.

Further, instead of providing an exhaustive list of all factors that might be relevant, the goal has been to provide a cohesive model that is efficient to apply. This does, however, mean that there might be factors that relate to interoperability or vendor lock-in, but that have not been included in the conceptual model.
One such factor might be the corporate culture a company operates in, as different national cultures have different values (Hofstede Insights, n.d.), and a vendor lock-in might be advantageous in the short term but disadvantageous in the long term. Although cases in different countries (and thus, different cultures) have been studied, such factors are beyond the scope of this thesis.
In addition, during the case study execution process, several factors were found that might play a role in the platform development process and the occurrence of vendor lock-in, but that were not included in the original conceptual model. These factors have been included in the revised conceptual model as an avenue of future research.

The factors that were included, were largely measured categorically. These measurements were based on the questions from Appendix IV: ‘Case Study Questions’, and these questions were in turn drawn from chapter 2. ‘Literature Review’, but this remains a more arbitrary process than the collection of enumerated statistical data. Ideally, the factors would be converted into such numbers – e.g. ‘architectural factor #1 contributes to vendor lock-in with 0.81’ – but this would take more thorough research and is beyond the scope of this thesis.

A related limitation is the fact that rounding has been applied to the categorical measurements, possibly removing nuance from the results of the case studies.
Another limitation pertaining to measurement, is that some values of variables were not measured at all. Of the five cases, no case scored ‘Low’ for ‘Platform Interoperability’ or ‘Data Standard Openness’. There has also been no case that used neither (or both) the ESPRESSO or FIWARE framework(s). Similarly, with only one case indicating a data market as the ideal outcome, this case might be an outlier. More cases will need to be investigated, to draw more certain conclusions.

Finally, and perhaps the most important limitation, is that smart city initiatives are not very mature yet. As noted in Appendix I.I: ‘City’, most smart city initiatives remain in early phases, before the adoption or implementation of technologies. For these smart cities, measuring ‘API Openness’ or ‘Architecture Openness’ may be problematic; they might have thought about various aspects and might have documented various ideas, but there may not yet be practical result.
Similarly, the dependent variable – vendor lock-in – is measured based on the subjective estimation of the interviewee. Interviewees could speak of past occurrences of vendor lock-in, and could gauge how their approach to their smart city initiative might impact future occurrences, but this remained a prediction. Smart city initiatives have generally not been realised to such an extent that a past situation could be compared to a present situation, so as to draw objective conclusions regarding vendor lock-in. None the less, three distinct strategies have been found by analysing the current and the predicted vendor lock-in.

6.3 Directions for Future Research

In addition to the conclusions, a set of recommendations for future research is given.

First of all, the revised conceptual model needs to be tested. A replication of this study would contribute to the generalisability of this thesis’s result, but it is recommended to do so in a setting that addresses the limitations mentioned in the previous paragraph.
For example, no cases were investigated with a score of ‘Low’ for ‘Platform Interoperability’ or ‘Data Standard Openness’, and only one case was investigated with a ‘data market’ ideal outcome. Increasing the number of cases studied would support or reject propositions with more certainty, and might provide new insights besides.
Further, to account for the maturity of smart city platforms, this should not be a cross-sectional study; each platform follows a different development process, and the actual level of vendor lock-in after the platform development process must be observed to properly draw conclusions.

Various propositions require further research. Despite many being rejected through the case studies, it is hypothesised that this is because smart city platforms are not sufficiently mature yet.
In particular, two new propositions have been found throughout the case studies:

1. A ‘data market’ ideal outcome positively moderates the relationship between ‘Platform Interoperability’ and ‘Application Openness’.
2. The FIWARE framework positively moderates the relationship between ‘Platform Interoperability’ and ‘Application Openness’.

Both of these require further research as well.

‘Platform Governance’ is an important variable that requires more research. As a first step, it is suggested to consult the chapter ‘Platform Governance’ of Tiwana, A. (2014: 118-151).
Similarly, the variable ‘Maturity’ requires research. It could be measured by using the Smart City Strategic Growth Map (ESPRESSO, 2016), or by using the evolutionary framework of Tiwana, A. (2014).
Finally, the variable ‘Contractual Obligations’ requires further research.

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Appendix

Appendix I: Supplemental Literature

Below a selection of supplemental literature to expand upon terms and concepts raised throughout the thesis.

Appendix I.I: City

The concept of a city is intuitively familiar yet hard to concretely define. Per the United Nations (2016): "Most people can agree that cities are places where large numbers of people live and work; they are hubs of government, commerce and transportation. … So far, no standardized international criteria exist for determining the boundaries of a city and often multiple different boundary definitions are available for any given city."

Dictionary definitions such as "an inhabited place of greater size, population, or importance than a town or village" (Merriam-Webster) or "a large town" (Oxford Dictionaries) are exceedingly vague and are either contradicting (are cities large towns, or are they larger – of greater size – than towns?) or seek to define the word by an equally nebulous term (what is a town?).
Indeed, 'town' is defined as "a compactly settled area usually larger than a village but smaller than a city" (Merriam-Webster) or "a built-up area with a name, defined boundaries, and local government, that is larger than a village and generally smaller than a city" (Oxford Dictionaries). This remains vague, as 'usually' and 'generally' indicate exceptions, and the original problem remains; 'city' is being defined in relation to 'town', whereas 'town' is defined in relation to 'city'.
Further, there are historical differences; Oxford Dictionaries differentiates between the British city (a town became a city by charter, and usually had a cathedral in it) and the American city (a municipal centre incorporated by the state or province). Merriam-Webster also states that British cities usually have the status of an episcopal see.

The United Nations (United Nations, 2016) describes three definitions; the city proper, the urban agglomeration, and the metropolitan area.
The city proper encompasses the smallest area and refers to the administrative boundary of the city.
The urban agglomeration encompasses a larger area, as it refers to the contiguous area of urban agglomeration around the city's administrative boundaries.
Finally, the metropolitan area encompasses the largest area, as it refers to the degree of economic and social interconnectedness (e.g. commerce or commuting patterns).
While the United Nations endeavours to use the urban agglomeration definition, it further notes that this is very often not possible, making it unknown to which of the three definitions the statistics drawn from the United Nations' sources adhere.

Given the concept of 'smart city' and related notions such as 'the city as system of systems' or 'the city as a geographic area' (e.g. Burns, 2017; European Commission, 2017: 15), the metropolitan area is the most useful definition when thinking of smart cities.
Mulligan and Olsson (2013) define smart cities as "cities that integrate a digital infrastructure with the physical city in order to reduce environmental impact while improving quality of life and economic prospects." Similarly, Schaffers et al. (2011) note that smart cities are a response to challenges regarding socio-economic development and quality of life, underlining this thesis's introduction.

Further underlining this thesis's introduction, however, is the notion that 'smart' is an ill-defined term; what makes a city smart, and what makes an application or service smart? Is it enough to put a sensor in an object, to make it a smart object? In general, smart cities have become possible largely because of cheaper and more ubiquitous sensor technology (Mulligan and Olsson, 2013). But some smart city initiatives revolve around putting sensors into objects and generating data, only afterwards developing this new capability into a practical use case, instead of the other way around (Appendix II: ‘Interviews’, VI).

As such, most smart city initiatives remain in early phases, before the adoption or implementation of technologies (Wagenaar, 2016; Andriessen, 2017). As Mulligan and Olsson (2013) note; the deployment of smart city applications and services is hindered by opposing architectural approaches to data management and service creation (see 2.3 ‘Platform Ecosystem’).

Although not all smart cities involve a unifying platform as of yet, most smart city platforms share certain commonalities that make interoperability desirable. The European Innovation Partnership on Smart Cities and Communities (the EIP-SCC) has defined these commonalities as part of the reference architecture. Per the EIP-SCC Open Urban Platforms (Heuser et al., 2017):

- New smart city platforms may reuse (parts of) existing smart city platforms (increasing efficiency of development).
- Smart city platforms may be shared by groups of (smaller) cities or communities after being developed (making smart city platforms feasible for smaller cities).
- Similar smart city platforms provide consistency towards stakeholders pertaining to e.g. data handling, privacy, security, and transparency (enabling citizens to move freely from one city/platform to another).
- Smart city platforms become more valuable to vendors as they can develop a standardised product fit for multiple smart city platforms (increasing competition and lowering costs).

Should each smart city deployment rely on a set of common interfaces and features (e.g. using REST APIs), the ‘distance to interoperability’ can be minimised (Bhatt et al., 2017).

Appendix I.II: Architectural Frameworks

This paragraph gives deeper insight in the architectural frameworks part of the platform ecosystem, as mentioned in paragraph 2.3 'Platform Ecosystem'; ESPRESSO and FIWARE.

All the information contained in this paragraph, unless specified otherwise, comes from personal interviews with a variety of persons (primarily Appendix II: 'Interviews', V, VI, and VII).
Even though multiple sources have been used, this can still lead to biases. For example, some sources draw dichotomous comparisons between ESPRESSO and FIWARE – e.g. loosely-coupled systems versus tightly-coupled systems, where modular systems stimulate innovation, or a bottom-up consensus approach versus a top-down theory-driven approach, where the theory-driven approach may result in a perfect feature but only after too much time has passed – while other sources disagree. As this paragraph merely serves to provide information about ESPRESSO and FIWARE, such subjective comparisons have largely been left out. As far as these factors are relevant, they would be found as part of the cross-case analysis.

In general, the many parties involved with these architectures cooperate closely on a variety of levels. FIWARE, for example, is a technology analysed through the CPS Framework, employing the PPIs of the WS2 Reference Architecture, which bear a close relation to the Minimal Interoperability Mechanisms (MIMs) of ESPRESSO.

ESPRESSO

ESPRESSO arose from a request of the European Commission concerning standards; which standards exist in smart cities, which standards should be used, and what is their (social, economical, et cetera) impact? During this process, ESPRESSO started looking at the 'urban platforms' of the EIP-SCC. ESPRESSO thence became a 'Coordination and Support Action' (CSA) to the EIP-SCC (for example, a capability map and reference architecture was made in cooperation with each other).

The MIM approach establishes the minimal set of interoperability mechanisms that gives users just enough to link systems together when they need to. Such loose couplings can patch and stitch together systems, and over time, pave the way for tighter and more validated couplings. In this sense, it differs from a 'grand design' approach, which attempts to create a comprehensive specification and architecture that encompasses every conceivable aspect of a city (Brynskov, 2017).
The MIM approach is in essence similar to the concept of PPIs; looking at what the industry at large is doing and defining these as PPIs to minimise the boundary to integration. If a developer knows that almost everyone is using XML or JSON syntaxes for data exchange, the developer can design his application to allow for integration through these two technologies.
Similarly, a smart city doesn't need to worry about providing a great variety of means to interface between applications and services, furthering cross-city adoption. This modularity is suspected to stimulate innovation, as it fosters a market where companies can compete to develop small components.

The difference between PPIs and MIMs lies in the different layers of the Hamburger Model:

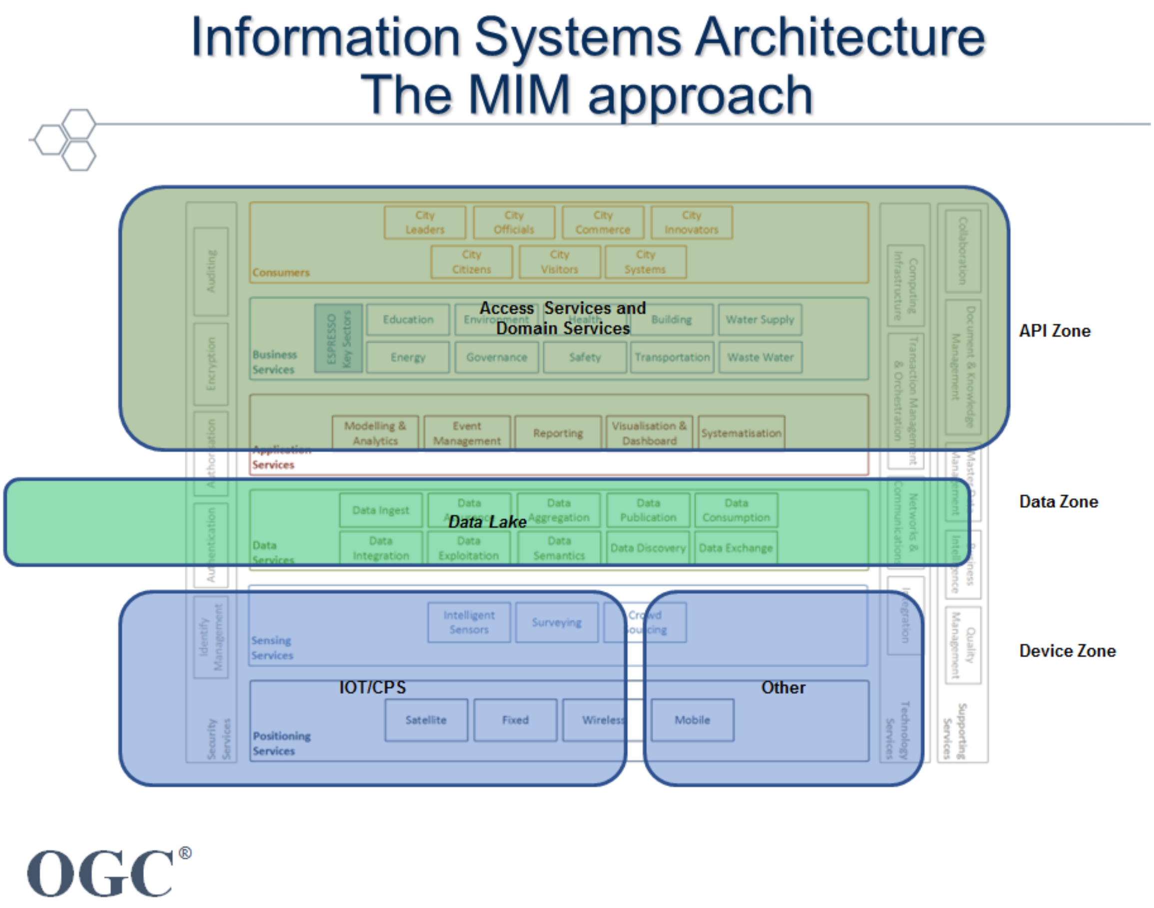

Figure 3: Hamburger Model

A very simplified explanation of the three layers applied to the Hamburger Model is as follows. The 'IoT/CPS' layer (or 'Device Zone') is where the sensors are, the 'Data Lake' layer (or 'Data Zone') is where they are maintained and where their output is stored, and the 'Access Services and Domain Services' (or 'API Zone') is where this output is used.
As part of the WS2 Reference Architecture, the interfaces between the 'Data Lake' layer and the 'IoT/CPS' layer were analysed. While as part of ESPRESSO, the interfaces between the 'Data Lake' layer and 'Access Services and Domain Services' layer were analysed. The former are PPIs, the latter are MIMs. When the two parties became aware of each other's efforts, they respectively adopted the terms 'south-bound' (PPI) and 'north-bound' (MIM) for this.

The idea behind this, is that any (vertical) silo (a closed-off system unable to interoperate with others) should be cut in the 'Data Lake' layer. There might be a silo in the other two layers, but the priority for interoperability goes to how the data is provided and made accessible in the 'Data Lake' layer.

ESPRESSO consists of multiple 'Workpackages' (WPs). They can be viewed as a process, with the output of one WP being the input for the subsequent WP (for more information, view: http://espresso-project.eu/content/deliverables/). Some of them are expanded upon below, as they provide some key insights that were taken into account during the case studies. Summarised, these insights were:

- The silo creation of Standard Developing Organisations (literature suggests commercial companies are most at risk of creating silos);

- The importance of open data to prevent a vendor lock-in (literature suggests open APIs are the most important aspect to prevent a vendor lock-in);
- The relation between and the information within various related aspects (e.g. CASSIOPEIA, the WS2 Reference Architecture, the Smart City Growth Map).

Workpackage 2: Smart City Interoperability Context

Workpackage 2 is described as the 'what' and as the scope.
This involves looking at sectorial systems (e.g. energy, transport, health) and comparing the 'smart city' version (e.g. smart energy) with the 'ordinary' version. However, there are no definitions of what exactly constitutes as 'smart energy' as opposed to the 'ordinary' energy sector (as already indicated in paragraph 1.1 'Motivation').

With storyboarding, in cooperation with Rotterdam (amongst others), use cases were defined within these sectorial systems (after which a gap analysis was conducted and pilots were explored). Based on these use cases, a conceptual interoperability framework was developed (CASSIOPEIA; ConceptuAl StandardS InterOPErabIlity frAmework). This framework defines the concepts of interoperability, but not the specific standards. Analogically, this is the difference between wanting to taste a spicy flavour (concept) and choosing hot peppers as ingredients (specific standards).

The framework contains more information on the aforementioned sectorial systems (Parslow, 2016: p.15-20). It also underlines various conclusions made so far, such as a discussion on what exactly a smart city is and the combination of a top-down and bottom-up approach (Parslow, 2016: p.21-22), and it was for example taken into account during paragraph 2.5 'Interoperability'. It was further taken into account during the creation of the conceptual model and the conduction of the case studies.

Workpackage 3: Smart City Standards Streamlining

Workpackage 3 is described as the 'how'.
This is about the specific standards and the organisations concerning themselves with these standards; what are they doing?
Four Standard Developing Organisations (SDOs) exist within ESPRESSO; the OGC (Open Geospatial Consortium), ETSI (European Telecommunications Standards Institute), buildingSMART, and DIN (Deutsches Institut für Normung).
In general, SDOs include both official (national or international) organisations, such as the ISO (International Organization for Standardization), but also industry consortiums, such as the OGC, the IEEE (Institute of Electrical and Electronics Engineers), and the W3C (World Wide Web Consortium). Many of these SDOs attend each other's meetings and try to work very closely together, to inform each other of what they are doing and to learn from each other.

ESPRESSO (and these SDOs) has informed cities that they are stuck with 'silo solutions' or 'point solutions'; they generate data, save it, and use it with an application within the context of their smart city. But this data can't be moved to (or used) outside of this context; a form of vendor lock-in. This is problematic when initiatives such as EU Ruggedised have cross-city interoperability as an explicit goal.

However, SDOs themselves inadvertently create such silos; a variety of SDOs exist within each sectorial system, and multiple technical committees exist within some SDOs. As such, there are many initiatives that concern themselves with standardising the same things (or at least, there is a lot of overlap). They try to work together, but there are too many such initiatives to align everything. When people do try to align these initiatives, this informal team of people willing to work together

inadvertently becomes their own 'silo' within the larger organisation(s). This is because (in this context) an SDO is an organisation others can be members of, and for example, members of the OGC physically meet up four times a year.
However, this is a relatively recently discovered problem. Gradually being more aware of this problem, efforts can be undertaken to counteract it (for example, W3C now has a subcommittee within OGC to align certain efforts).

Workpackage 4: Development of Smart City Information Framework

This workpackage involves the technical goals and contains the WS2 Reference Architecture.
Part of these technical goals is the development of a shared vocabulary for smart cities; 'open data' is an important aspect for smart city interoperability (Minguela, 2016; Walter and Woodling, 2017).
Starting from the premise that harmonising all the different data models is impossible, Linked Open Data is explored as a solution. 'Linked Data' is a term coined by the director of W3C in 2006 (Berners-Lee, 2006), and the addition of 'open' means that it is released under an open license that does not impede its free reuse.
Linked Data arose in the context of the Semantic Web, an extension of the World Wide Web (WWW) built on W3C standards in which data present on web pages is structured so that computers can directly analyse it. This is reminiscent of how HTML represents relationship anchors in hypertext documents, allowing humans to look up related terms by clicking on a hyperlink.
In this context, pertaining data, the Resource Description Framework (RDF) data model is used as the standard vocabulary, to provide semantic annotation through triples. A triple describes semantic data in the form of subject-predicate-object, and is comparable to the way a traditional entity-relationship model works; 'this thesis' (subject) 'is' (predicate), 'being read' (object), versus 'thesis' (entity), 'status' (attribute), 'being read' (value). Each individual part of this triple is a Uniform Resource Identifier (URI, of which a URL – a Uniform Resource Locator – is the most common form); 'thesis', for example, could refer to the Wikipedia page about theses. In this way, every classification can be described to create a connected ontology. However, a shared vocabulary has to be agreed upon, and this has not yet been standardised (although examples such as RDF Schema exist).

Tangentially related is the Smart City Strategic Growth Map (ESPRESSO, 2016), which dedicates a fair amount of questions to the access to and the strategy of data (as well as standardisation). With these questions (amongst others), the City Maturity Model maps a specific smart city on a maturity level ranging from 'no or limited data strategy' to 'full understanding of city data value'.
The ESPRESSO framework inherently views aspects related to interoperability as characteristics of mature smart city platforms. Given the importance placed on open data and related concepts, the more technical orientation on data and the relevant questions of the Smart City Growth Map will be used to better conduct this thesis's proposed case study (Appendix IV: 'Case Study Questions').

This workpackage also includes the WS2 Reference Architecture; an open, referenceable, and composable framework meant to integrate various key components of smart cities (e.g. mobility or energy) in such a way that applications and services can be combined with previously existing capabilities. A very broad overview is shown on the next page:

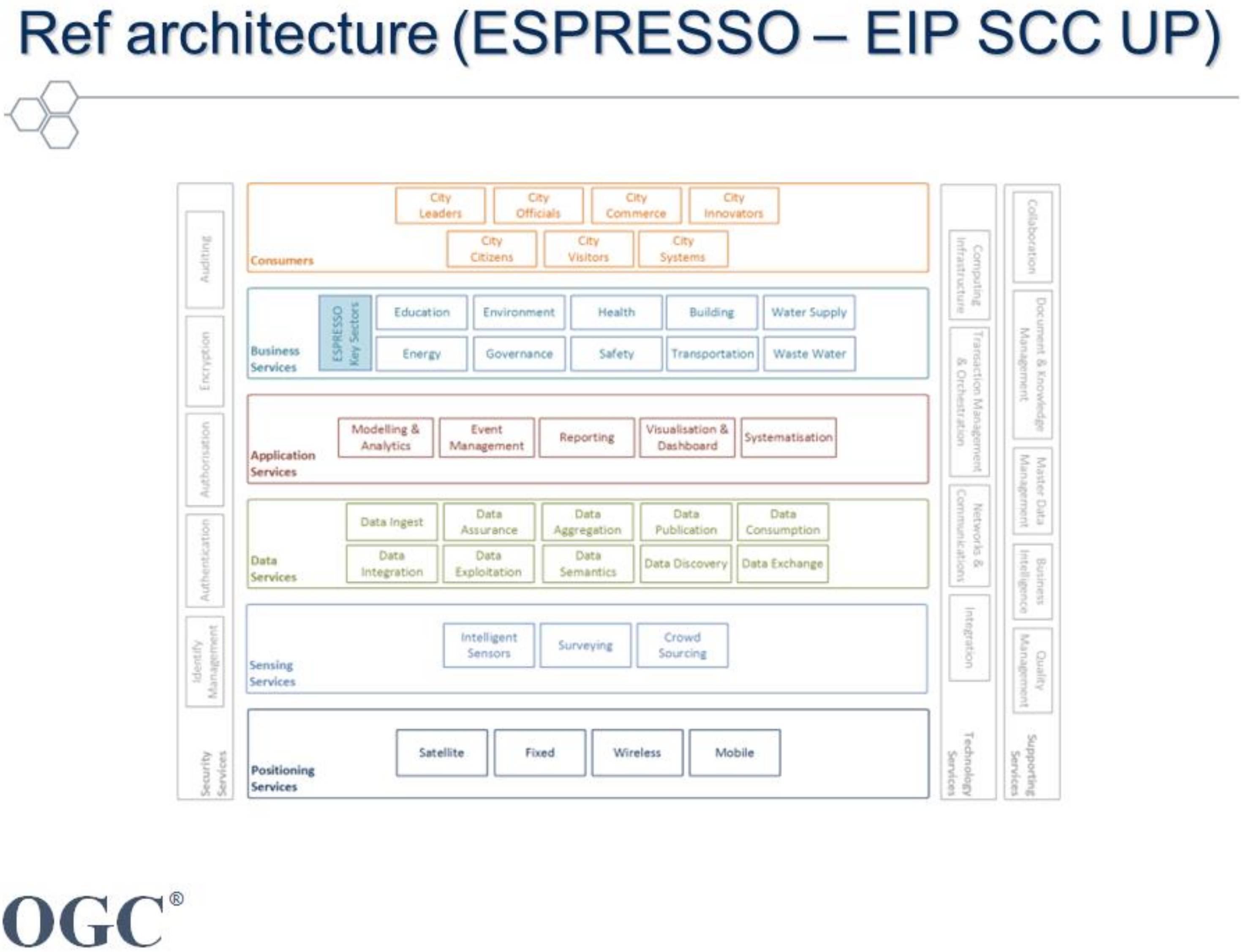

Figure 4: WS2 Reference Architecture

Alliander N.V. works within EIP-SCC, and was doing something similar to ESPRESSO. It would have been problematic if Alliander and ESPRESSO, working separately, didn't come to a shared result. As such, upon becoming aware of their efforts, they combined their work (and involved other parties) to eventual deliver the reference architecture (Heuser et al., 2017).
The Hamburger Model originates from this reference architecture, as well as a capability map that includes standards related to smart cities (CASSIOPEIA). 16.700 ‘standards’ were estimated, but it is suspected that this is an underestimation by a factor hundred. For more detailed information, it is advised to read the document itself (Heuser et al., 2017).

FIWARE

FIWARE (Future Internet Ware) is a public-private initiative of the EU, launched in 2011, to make Europe more innovative and competitive.
FIWARE consists of two parts; a technology-based part concerning open source 'generic enablers', and a process-based part to further innovation.

To this end, FIWARE launched 'labs' in various cities, among them being Utrecht (with Nice and Göteborg – the other two lighthouse cities of the IRIS initiative – also being interested). With the FIWARE labs, start-up companies can test their ideas using FIWARE's generic enablers (open source, in that a free license is needed, so as to keep track of who used or modified what). Then, start-up companies can show their working prototype to municipalities and other interested parties, and for example gain funding to implement their ideas. In addition to the low entry barrier, the generic enablers are designed to easily allow for 'scaling up'. That is, if a start-up company has successfully marketed their solution to one city, this solution should also be easy to implement in another city. As such, as more such solutions are built using generic enablers, generic enablers naturally become open standards.

However, many of the generic enablers were early versions that had long ceased being in development; they had been abandoned. To ensure the quality of the generic enablers, the original FIWARE project was cancelled as an independent initiative in 2017, and transferred to the FIWARE Foundation in Berlin. The FIWARE Foundation concerns itself with standards, data models, and certifications. This Foundation went through all the generic enablers (cooperating with, for example, the German research organisation Fraunhofer Society) to decide which ones were qualitatively mature. In this way, the generic enablers were classified.

TMForum is an organisation originating from the telecommunications industry. It covers aspects such as service level agreements between different providers, and for example facilitates the regulation of roaming charges within the EEA. This model – consisting of, amongst others, business frameworks and standards – was also found to be relevant for smart cities; many parties are involved, and many agreements need to be made, concerning many different subjects. As such, it is currently being 'translated' to apply to smart cities.
Part of this concerns open APIs. TMForum is selecting these based on what is currently being used. Some of these open APIs are taken from (and in cooperation with) the FIWARE Foundation, and FIWARE is trying to 'push' its generic enablers into TMForum so as to engender more support and adaptors. Whether an API classifies as ‘open’ depends on a wide range of factors; whether it is accessible online, whether an account is needed to access it, whether specific parties can be refused access, whether one first needs to sign a contract, whether data will be owned by the provider or the user of the API, and what kind of agreements exist in general.
In the end, it might be that the FIWARE Foundation ceases to exist in the near future, as its standards might then be integrated within TMForum. After all, FIWARE does not build new standards, but certifies existing ones, nor does it build new technology, as it uses open source components.

Civity is one of the organisations behind the FIWARE lab in Utrecht, and positions itself as a utility company that manages the infrastructure and logistics necessary for the use of open data within smart cities (i.e. to prevent vertical silos). To this end, Civity maintains the 'City Innovation Platform', which uses standards from FIWARE, the OGC, and TMForum. While in this context 'FIWARE' and 'Civity' are used interchangeably, it might be that for example the relation between FIWARE and ESPRESSO is more applicable to Civity in specific than to FIWARE as a whole.

FIWARE is more about the idea of innovation and cooperation, and about the interfaces between the generic enablers, than about which specific kind of technology should or should not be a standard. Much like ESPRESSO, the view is that there can be multiple standards (e.g. LoRa in the Netherlands and SigFox in France, both being Low-Power Wide-Area Network technologies). Where ESPRESSO defines PPIs and MIMs, FIWARE defines generic enablers, both to facilitate interfaces between technologies. In addition, FIWARE also defines common data models to facilitate the exchange of data. FIWARE combines a variety of different datasets, and translates them to certain output formats (the chosen standards), so that other parties can easily access these datasets.

FIWARE uses ESPRESSO as a broader, more strategic framework, to see which modules are missing or how visions might differ. ESPRESSO offers a capability map, while FIWARE can fill in these capabilities with – or translate them to – the generic enablers (in this sense, ESPRESSO is comparable to TMForum). But FIWARE also has its own agreements concerning data management; ESPRESSO and FIWARE are not necessarily on different levels, but FIWARE is more focused on data and on development tools, while ESPRESSO takes a broader perspective with its capability map.
A mapping between the two is still work in progress, but it is thought that ESPRESSO and FIWARE would be good to use in combination with each other (this is also what Utrecht intends to do).

Appendix I.III: Cyber-Physical Systems Framework

CPS is a term that can be used interchangeably with IoT (Internet of Things).
'CPS' refers to 'cyber-physical systems': "Cyber-physical systems integrate computation, communication, sensing, and actuation with physical systems to fulfil time-sensitive functions with varying degrees of interaction with the environment, including human interaction." (Cyber Physical Systems Public Working Group, 2015).
Or: "Cyber-Physical Systems (CPSs) are complex, multi-disciplinary, physically-aware next generation engineered systems that integrate embedded computing technology (cyber part) into the physical phenomena by using transformative research approaches" (Gunes et al., 2014).

The work of a consortium consisting of the USA-based National Institute of Standards and Technology (hereafter 'NIST'), the lead partner, and various other partners (amongst which ANSI, ENEA, ETSI, FIWARE, MSIP, and USGBC)

Although the work of the consortium concerns itself with CPS, the delivered CPS Framework, including the PPIs, is equally applicable to IoT. As such, it is both applicable to smart cities and to certain other multi-sided platforms (Cyber Physical Systems Public Working Group, 2015). In conclusion, PPIs originate from the desire to standardise interfaces of Cyber-Physical Systems; IoT-based platforms.

In order to standardise these interfaces of IoT-based platforms, the CPS Framework is used to reduce architectures to the so-called 'CPS Framework Normal form', which exposes potential PPIs. For example, even though (IoT) developers may not have been aware of PPIs, in practice, many have made the choice to use IPv6 addresses to identify communication end-point addresses. By noting this as a PPI, platform owners might be inclined to include this as a requirement for the applications on their platform, and developers might be inclined to adhere to this out of their own volition. This would then reduce the 'distance to interoperability' (Bhatt et al., 2017). As such, PPIs are not enforced standards, but consensus-based standards; not by mutual agreement but by independent election (Bhatt et al., 2017).

Referring to the simplified Hamburger Model (see Appendix I: 'Supplemental Literature'), the consortium behind the WS2 Reference Architecture is now establishing 'north-bound' and 'south-bound' PPIs.
'North-bound' refers to PPIs in between the 'Data Lake' layer (or 'Data Zone') and 'Access Services and Domain Services' layer (or 'API Zone'). These are for example HTTP and JSON.
'South-bound' refers to PPIs in between the 'Data Lake' layer (or 'Data Zone') and the 'IoT/CPS' layer (or 'Device Zone'). These are for example LoRa or CSV.
Although these are examples of very specific technology, the methodology behind exposing PPIs would none the less serve as a useful starting point for finding relevant smart city platform architectural factors.

The CPS Framework consists of domains, concerns, properties, aspects, and facets (Cyber Physical Systems Public Working Group, 2017):

- Domains represent different application areas, such as energy or healthcare.
- Concerns are expressed by stakeholders and are addressed throughout the CPS development cycle. Conceptually equivalent (or similar) concepts are grouped into aspects.
- Properties address concerns, and include requirements, design elements, tests, and judgements.

- Aspects consist of groupings of conceptually equivalent (or related) concerns. Nine aspects exist; functional, business, human, trustworthiness, timing, data, boundaries, composition, and lifecycle.
- Facets are collections of activities that produce artefacts driven by aspects and concerns for a CPS. They encompass identified responsibilities and contain activities and outputs to address concerns (e.g. conceptualisation, through defining use cases or requirements, leads to a model of a CPS). Three facets exist; conceptualisation, realisation, and assurance.

The methodology behind exposing PPIs is based on 'zones of concern'. This is a concept related to where sets of technologies may apply; the communication requirements (concerns) for connecting a sensor to a mobile network are different from the communication requirements for connecting a mobile phone application to a cloud service provider. The technology is analysed for each such zone of concern, by referring to where and how the zone of concern is addressed in the technology's documentation. By combining all these analysations, patterns of similar concerns and similar solutions may be revealed; candidates for PPIs. This is a work in progress, as no conclusive list of PPIs has been established as of yet (Bhatt et al., 2017; Appendix II: 'Interviews', II).

Appendix II: Interviews

Below an overview of the interviews held to arrive at the end result. This overview only includes those interviews that have been cited in this thesis (I to VIII) and the case studies (IX to XIV).

ID	Date	Interviewee(s)	Function
I	12 January 2018	Roland van Ravenstein	Corporate Account Director (KPN)
II	4 February 2018	Martin J. Burns	National Institute of Standards and Technology, Smart Grid and Cyber-Physical Systems Program Office, Associate Director for Testbed Science
III	20 February 2018	Martin J. Burns	National Institute of Standards and Technology, Smart Grid and Cyber-Physical Systems Program Office, Associate Director for Testbed Science
IV	26 February 2018	Thomas Kruse	Strategy Advisor Business Management (Utrecht)
V	12 March 2018	Roland van der Heijden	Product Manager Digital City
VI	27 March 2018	Bart de Lathouwer	General Manager and Director Innovation Program of the Open Geospatial Consortium
VII	30 March 2018	Arjen Hof	Director of Civity
VIII	24 April 2018	Roland van der Heijden	Product Manager Digital City (Rotterdam)
IX	24 April 2018	Roland van der Heijden	Product Manager Digital City (Rotterdam)
X	14 May 2018	Bauke Keulen	Team Manager and Strategical Advisor Information Management (Amersfoort)
XI	18 May 2018	Thomas Kruse	Strategy Advisor Business Management (Utrecht)
XII	23 May 2018	Janette van Dijk	Project Manager Smart City (Amersfoort)
XIII	23 May 2018	Gavin Slater Ciaran Higgins	Group Manager – City Energy & H2020 Ruggedised Lead Director at Derryherk Limited
XIV	28 May 2018	Carina Aschan	Project Manager RUGGEDISED

Table 9: Overview of Interviews

Appendix III: Questionnaire

Below part of the questionnaire sent out on the ninth of April, 2018, to get a broad-level overview of where smart cities within the EU are at the moment (the full questionnaire is available on request).

As such, this questionnaire was sent out to a multitude of smart cities within the EU, all part of various EU-wide initiatives alike to EU Ruggedised or IRIS. They are divided between so-called 'lighthouse cities' (those that will implement new practices first), 'follower cities' (those that will implement new practices later, learning from the lighthouse cities), and sometimes 'observer cities' (their exact role differs per project, but in general consists of merely observing, as an affiliated party). In specific, they are:

Lighthouse cities: Amsterdam, Antalya, Barcelona, Bristol, Cologne, Dresden, Eindhoven, Florence, Glasgow, Göteborg, Grenoble, Hamburg, Helsinki, Lisbon, London, Lyon, Manchester, Milan, Munich, Nantes, Nice, Nottingham, Pamplona, Rotterdam, San Sebastian, Sonderborg, Stavanger, Stockholm, Tampere, Tartu, Tepebasi, Trento, Umeå, Utrecht, Vaasa, Valencia, Valladolid, Vienna, Vitoria-Gasteiz
Follower cities: Alexandroupolis, Asenovgrad, Belfast, Bordeaux, Brno, Burgas, Bydgoszcz, Cluj-Napoca, Cork, Derry, Dubrovnik, Essen, Foscani, Gdańsk, Graz, Herzliya, Izmir, Kerava, Klaipeda, Kozani, Lausanne, Lecce, Leipzig, Litomerice, Menorca, Miskolc, Nilüfer, Ostend, Palencia, Parma, Porto, Prague, Rijeka, Roeselare, Sabadell, Santa Cruz De Tenerife, Santiago de Compostela, Seraing, Seville, Skopje, Sofia, Suceava, Vaasa, Valletta, Varna, Venice, Warsaw
Observer cities: Kiev, Tianjin, Yokohama

Specifically for this thesis, the below part of the questionnaire gave insight into a smart city's platform architecture and vendor lock-in, and was used for the case selection:

What approach best describes how your smart city is being developed (if neither, please explain in the subsequent open question)?

1	2	3
Bottom-up, demand driven, individual use cases may or will eventually be unified on a platform.	,	Top-down, overarching platform, allows for a variety of use cases (services) to eventually be on the platform.

What are your reasons for this approach?
[…]

What situation best describes the envisioned result of your smart city (if neither, please explain in the subsequent open question)?

1	2	3
A data market where everyone can pull data from.		A digital community where everyone can use and develop services and applications.

What are your reasons for desiring this outcome?
[…]

What architectural framework best describes your smart city (if neither, please explain in the subsequent open question)?

1	2	3
An integrated and controlled system in which modules are documented and developed by a private party, guaranteeing the quality of these modules when working together (e.g. FIWARE).		A set of interface-related standards that are already widely in use, allowing other parties to develop their own products while accounting for these standards (e.g. ESPRESSO's MIMs and PPIs).

What are your reasons for choosing this architectural framework?

[…]

How likely do you think it is to encounter a vendor lock-in?

For example, if you are using four modules from one developer, how free are you to use a fifth module from a different developer?

Similarly, if someone has developed an application for your platform, how free are you to use the data that this application has generated?

1	2	3	4	5
Unlikely				Likely

Please expand upon your reasons for choosing the above answer:

Perhaps you have taken certain measures to prevent a vendor lock-in from occurring, such as using design principles for certain components (e.g. infrastructure, data sources, service hubs, applications and services, users)?

[…]

Should you encounter a vendor lock-in, how high do you expect switching costs to be?

1	2	3	4	5
Low (time)				High (time)

1	2	3	4	5
Low (money)				High (money)

Appendix IV: Case Study Questions

Below an outline of the information to be gathered about the selected cases. For readability, the questions below are ordered by topic, but this does not mean that a question of one topic cannot provide insight into a different topic; whether a standard vocabulary has been adopted can give insight in 'interoperability' and in 'data standard openness'.

The source of each question is indicated in brackets (where for example 'SCSGM 1' indicates the first aspect from the Smart City Strategic Growth Map; 'City Strategy').

Vision

1. Do you have a clear vision of what you'd like your city to look like in the future? (SCSGM 1)
2. Do you have a set of goals, priorities and actions? (SCSGM 1)
3. Do you know what main challenges your city needs to address? (SCSGM 1)
4. Do city stakeholders and city users have input into your city vision? (SCSGM 1)
5. Is your vision being revised regularly in light of both the changing urban environment and the availability of technological solutions? (SCSGM 1)
6. Is your strategy citizen centric? (SCSGM 1)
7. Do you have established a common terminology agreed among all city stakeholders? (SCSGM 1)

Interoperability

1. Does the platform use a common set of non-proprietary standards? (paragraph 2.5 'Interoperability')
2. Are the standards freely redistributable without restricting any party from distributing a standard as part of for example a software distribution? (paragraph 2.5 'Interoperability')
3. Are standards revisable by any party in an open process? (paragraph 2.5 'Interoperability')
4. Are there platform-wide open (interface) specifications (a collection of open specifications that define the APIs for high-availability applications)? (paragraph 2.5 'Interoperability')
5. Does the platform not discriminate against any individual or group? (paragraph 2.5 'Interoperability')
6. Is the platform technology neutral; does it not require a specific type of underlying platform, database, or interface? (paragraph 2.5 'Interoperability')
7. Have you agreed on common interfaces and standards with other smart cities? (paragraph 2.5 'Interoperability')
8. Do you procure systems together with other smart cities? (paragraph 2.5 'Interoperability')
9. Does a gatekeeper-role exist – e.g. is all data integrated in one silo as opposed to kept in closed, vertically integrated systems that are not interoperable with other cities? (paragraph 2.5 'Interoperability')
10. Have you adopted (or encouraged the adoption of) smart city vocabularies? (SCSGM 8, paragraph Appendix I.II: 'Architectural Frameworks')
11. Does your city use standards-based ICT equipment? (SCSGM 7)
12. Have you engaged with a national or an international SDO smart city developments? (SCSGM 8)
13. Are you using standards to break down silo operations in government and industry (SCSGM 8)?

Resilience

1. To which degree can a subsystem in the platform maintain an acceptable level of service when there is a disruption in another subsystem or in an external service? (paragraph 2.6 'Resilience')
2. Are applications loosely coupled with the platform through interfaces that do not change over time? (paragraph 2.6 'Resilience', Appendix I.II: 'Architectural Frameworks')

3. Are platform-app dependencies kept to a minimum? (paragraph 2.6 'Resilience')
4. Does the platform use modular interfaces to interface with externalities? (paragraph 2.6 'Resilience')
5. Does the platform incorporate redundancy for external services (e.g. allow for both 3G and WIFI for data transport)? (paragraph 2.6 'Resilience')
6. What is the average recovery time of the platform (or an app) after a failure outside of the platform? (paragraph 2.6 'Resilience')
7. Describe your platform-governance alignment? (paragraph 2.6 'Resilience')

Data Standard Openness

1. Are open formats used for data interchange? (paragraph 2.4 'Vendor Lock-In')
2. Do applications make use of mutually interoperable data formats and data stores? (paragraph 2.4 'Vendor Lock-In')
3. Are users allowed to mutate and export the data? (paragraph 2.4 'Vendor Lock-In')
4. Are data analytics applied on combined data sets to acquire new insights support, service delivery, information sharing or the better utilisation of resources? (SCSGM 5)
5. Have data management standards and processes been implemented? (SCSGM 5, paragraph 2.4 'Vendor Lock-In')
6. Have you made interoperability key to your successful data strategy? (SCSGM 5, paragraph 2.4 'Vendor Lock-In')
7. Have you reached agreements with partners about data sharing, data privacy and data management policies? (SCSGM 5, paragraph 2.4 'Vendor Lock-In')
8. Do you continually monitor, review and develop data processes in an agile manner? (SCSGM 5)
9. Are you making city data openly available to the wider public? (SCSGM 6, paragraph 2.4 'Vendor Lock-In')
10. Are you operating a data platform for open data? (SCSGM 6)
11. Did you consider user-friendliness when designing the data portal? (SCSGM 6, paragraph 2.4 'Vendor Lock-In')
12. Do physical and virtual spaces exist to support city data communities? (SCSGM 6)
13. Do you have data sharing targets and performance measures? (SCSGM 6, paragraph 2.4 'Vendor Lock-In')
14. Did you engage with organisations inside and outside of government to overcome data sharing barriers and make access to data fully operational? (SCSGM 6)
15. Is all city data available through a single data hub, including data from government services and external stakeholders (such as utilities)? (SCSGM 6)
16. Is your data shared widely across departments? (SCSGM 6)
17. Are your performance metrics accessible to the public? (SCSGM 6)
18. Is data published to agreed formats? (SCSGM 6, paragraph 2.4 'Vendor Lock-In')

API Openness

1. Do applications have (the theoretical ability to have) programmatic access to each other; can applications communicate and interact with each other? (paragraph 2.4 'Vendor Lock-In')
2. Is the API (publicly) accessible online? (paragraph 2.4 'Vendor Lock-In', Appendix I.II: 'Architectural Frameworks')
3. Does the API require an account to access it? (Appendix I.II: 'Architectural Frameworks')
4. Can specific parties be refused access to the API? (Appendix I.II: 'Architectural Frameworks')
5. Do parties need to sign a contract before being allowed to access the API? (Appendix I.II: 'Architectural Frameworks')
6. Will data be owned by the provider or the user of the API? (paragraph 2.4 'Vendor Lock-In', Appendix I.II: 'Architectural Frameworks')

7. What kind of (and how many) agreements and regulations exist in general, concerning API access? (Appendix I.II: 'Architectural Frameworks')
8. Do you select suppliers based on their willingness to adopt standards that you have selected? (SCSGM 8)

Architecture Openness

1. Is the source code behind applications publicly accessible? (paragraph 2.4 'Vendor Lock-In')
2. Are applications and dependencies easily portable across platforms? (paragraph 2.4 'Vendor Lock-In', paragraph 2.5 'Interoperability')
3. Do applications rely on proprietary runtime programs, languages, frameworks, databases, libraries, or other third party services necessary for the application to function? (paragraph 2.4 'Vendor Lock-In')
4. Are applications (e.g. WordPress, Mendix) or frameworks (e.g. Symfony, Django) used for the development of applications? (paragraph 2.4 'Vendor Lock-In')

Documentation Transparency

1. Are requirements and deliverables documented? (paragraph 2.4 'Vendor Lock-In')
2. Is the option for extensibility documented? (paragraph 2.4 'Vendor Lock-In')
3. Is an exit strategy documented? (paragraph 2.4 'Vendor Lock-In')
4. Are commonalities and dependencies documented? (paragraph 2.4 'Vendor Lock-In')

Vendor Lock-In

1. How likely do you think it is to encounter a vendor lock-in (or; have you ever encountered a vendor lock-in)? (paragraph 2.4 'Vendor Lock-In')
2. Should you encounter a vendor lock-in, how high do you expect switching costs to be in terms of time? (paragraph 2.4 'Vendor Lock-In')
3. Should you encounter a vendor lock-in, how high do you expect switching costs to be in terms of money? (paragraph 2.4 'Vendor Lock-In')

Appendix V: Validity & Reliability

Below a summary of paragraph 4.4 ‘Validity & Reliability’ in table format.

Construct Validity	**Addressed by**
Use multiple sources of evidence	Holding multiple interviews for two out of five cases. Weaknesses of interviews are addressed in Appendix VII: ‘Weaknesses of Interviews’.
Establish a chain of evidence	Describing cases in detail, developing both within-case analyses and a cross-case analysis.
Have interviewees review a draft case study report	Forwarding a description of the interviewees’ case (similar to the results of chapter 5. ‘Case Studies’) and a colour-coded variant of Appendix IV: ‘Case Study Questions’ (to indicate how and why the case scored on each topic).
Internal Validity	
Pattern matching	Not fully used; falsifiable propositions were matched with patterns from the cross-case analysis, but this is a categorical (and not a numerical) endeavour.
Explanation building	Not fully used; the initial conceptual model is revised after the cross-case analysis, but not after each individual case.
Addressing rival explanations	Not fully used; rival explanations can only be formed as part of refining the initial theoretical propositions (the conceptual model), as no studies concerning these theoretical propositions exist as of yet.
Rely on theoretical propositions	Used; the theoretical propositions are reflected throughout the thesis. From the broad questions raised in chapter 1. 'Introduction', to the development of a narrower problem statement, and from to the broad range of reviewed literature to the narrow propositions and conceptual model, and finally to the data collection through very specific interviews.
Develop case description	Unused; this is a descriptive approach, likely resulting in a massive, unreadable document.
Logic models	Unused; this is a chain of cause and effect to give insight into variables underlying those of a proven conceptual model, but the goal is to test an unproven conceptual model.
External Validity	
Use replication logic	Conducting a multiple-case study guided by Appendix IV: Case Study Questions.
Case study protocol	Appendix VI: 'Case Study Protocol'.
Reliability	
Personal skills	Not assessed.
Training for a case study	Developing paragraph 4.3 'Case Study Design' and Appendix IV: 'Case Study Questions', and by conducting a pilot case study with the request for feedback on how the author conducted the case study.
Case study protocol	Appendix VI: 'Case Study Protocol'.

Screening of case study nominations	Paragraph 4.6 'Case Selection'.
Pilot case study	Conducting a pilot case study, on the 24th of April, 2018.
Case study database	Recording case study interviews, collecting and perusing additional information (e.g. suggested documents or websites), and developing a detailed narrative per case.

Table 10: Validity & Reliability

Appendix VI: Case Study Protocol

Below the case study protocol as discussed in paragraph 4.4.4 'Reliability', based on Yin, 2003: 69.

Case Study Protocol Components	Applied Within Thesis
An overview of the case study project	Chapter 1. 'Introduction' Chapter 2. 'Literature Review' Chapter 3. 'Conceptual Model'
Field procedures	Paragraph 4.5 'Research Methods'
Case study questions	Appendix IV: 'Case Study Questions'
An outline of the case study report	Table of Contents Chapter 1. 'Introduction'

Table 11: Case Study Protocol

Appendix VII: Weaknesses of Interviews

Below the weaknesses of interviews as noted by Yin (2003: 86), and how they have been addressed throughout the development of this thesis.

Weaknesses of Interviews	Addressed by
Bias due to poorly constructed questions	Developing Appendix VI: ‘Case Study Protocol’. Holding a pilot case study.
Response bias	Using clear language and framing questions in a neutral, unbiased way.
Inaccuracies due to poor recall	Recording the case study interviews, taking notes, and asking recap questions.
Reflexivity	Developing chapter 4. 'Research Methodology and paragraph 5.6 'Cross-Case Analysis', and discussing and inferring meaning from the case studies.

Table 12: Weaknesses of Interviews