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A Dutch telecom operator strategy design for 5G-related business innovation

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A Dutch telecom operator strategy design for 5G-related business innovation

Master Thesis

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Abstract

In anticipation of the new era of mobile technology that is 5G, operators are contemplating how they should act. In layered modular technical architectures, with markets that consist of nongeneric complements, there are many potential 5G-based innovations which could become successful. This creates a host of uncertainties, such as relating to which applications, and which components of those applications, will become successful, to how market- and technical architectures will be organized, and eventually to which actors will win. Furthermore, multiple dynamics are at play, such as that bottlenecks may change over time, as new solutions are discovered, or as actors manipulate markets. These uncertainties and dynamics, in turn make the creation and appropriation of value an uncertain business.

This thesis adopts a science-based design approach in order to inform an operator's strategy for 5G-related business innovation. Based on theory and practice, the context was established, and design principles were generated which should allow an operator to strategically behave in the specific context. Theory-based principles were acquired from academic literature, practice-based principles were derived from conducted interviews, and from other sources such as whitepapers from the industry. The theory-based and practice-based design principles were synthesized in order to create a final set of design principles. The generated set of design principles, and solution directions, serve to support the telecom operator in preparing itself strategically for 5G-related business innovation.

Summary

We are at the dawn of a new mobile infrastructure era, which is that of 5G. The combination of high speed, low latency, reliability, and the potential for carrying huge amounts of simultaneous connections, sets the stage for a digital revolution, by allowing for the creation of a vast array of new value propositions (Deloitte, 2018a; McKinsey, 2018a). These new value propositions are especially expected to be found in business settings.

This simultaneously creates a host of new challenges. It is uncertain which value propositions exactly will become successful, who will win, and how markets will be structured. The telecom operator finds itself in a tough spot. Historically, the operator has been organized to serve the mass consumer, so obviously it has to adapt to a new situation. Furthermore, enormous investments are required to be able to compete in new 5G markets, yet it remains uncertain if the operator will reap any benefits. Because of this, the operator has to deal with some uncertainty about how to move forward. This thesis research therefore focuses on designing a strategy for the Dutch operator, in settings of 5G-related business innovation. This issue is divided into two sub research questions, which are:

> SQ1: How can the context of 5G-related business innovations in the Dutch market, best be characterized?
>
> SQ2: How should telecom operators strategically act in that context?

In order to deal with these questions, a science-based design approach is adopted. A science-based design approach aims to generate prescriptive knowledge, in the form of solution concepts that prescribe what an actor should do in a given situation (Van Aken, Berends, Van der Bij, 2006). This prescriptive knowledge can be based both on what the theory prescribes in a specific situation, and on what is found in practice (Van Aken and Romme, 2012). The general approach that this thesis aimed for, was to develop a strategy design that is grounded both in theory and in practice, thereby adhering predominantly to the principles set out by Van Burg, Romme, Gilsing and Reymen (2008). The design principles that are developed, are formulated according to the CIMO-logic (Context, Intervention, Mechanism, Outcome) as specified by Denyer, Tranfield and Van Aken (2008).

In order to outline the context, open and semi-structured interviews were held with a diverse set of actors who are currently involved in 5G-related innovation, with the goal of addressing how the context of 5G is perceived in The Netherlands, and how operators should strategically act in that environment. Furthermore, based on initial empirical results, scientific literature was selected which was felt that best reflected that context. These papers were then used for a literature review, which led to a theoretical delineation of the context.

While still being in the stage of doing interviews and studying the literature, design principles were formed. These design principles not only served as an input to the design itself, but also acted as boundary objects such as described by Romme and Endenburg (2006). That is, these design principles connected the theoretical constructs put forth by the academic world, with the way in which actors in the empirical world perceive their world. Design principles identified by literature guided some of the topics discussed in interviews, and in other instances design principles allowed for a reinterpretation of the data from the interviews. Similarly, design principles were used as input for additional literature.

Finally, sets of theory-based and research-based design principles were generated. Based on the two sets, a synthesis was made, which led to the creation of a final set of design principles. These final design principles then formed the basis for some general solution directions.

The context of this thesis, was firstly characterized as one of a layered modular architecture. The important implication of this was, that in layered modular architectures, combinatorial innovation is possible, which allows for many potential complementary innovations to be created, on top of that layered modular architecture. This is therefore also, what also makes 5G a generative technology.

Due to this modularity as the coordinating mechanism, what in fact is created, are markets consisting of complements. From the perspective of the operator, this can be characterized as multi-sided markets, as different use sides develop complementary services, through the network of an operator. Furthermore, a critical characteristic of such market architectures, is that there always are components which hold more value, strategically, than others. These components are bottlenecks. Furthermore, interactions in these markets are found to be embedded in somewhat stable sociotechnical regimes. For instance, many organizations work with legacy systems, which would need to be altered in order to allow 5G-related innovations to be created.

In this context of layered modular architectures, with multi-sided markets consisting of complementary components, there are some inherent types of uncertainties. As the current market architectures for 5G-related business innovations are only just emerging, the eventual structures, bottleneck components, successful value propositions, and so on, are still very uncertain. In general, this uncertainty is exacerbated in layered modular architectures, due to its generativity. These types of uncertainty also make value appropriation and creation inherently more uncertain.

Finally, there are some typical dynamics which characterize this context. An important one, is that bottlenecks may change over time, as new solutions are discovered, or as actors manipulate the market- and technical architectures. Furthermore, there typically are some feedback dynamics in how complementary actors interact with each other, with for instance increases in momentum leading to increasing clarity.

Based on an outlining of this context, the main research question, on how operators should strategically act, can be answered according to specific design principles. These design principles are presented in the following table:

	Context	Intervention	Mechanisms	Outcome
DP1	Markets characterized by nongeneric complements	Increase modularity, by employing 5G technologies such as network slicing, SDN, and edge computing, by means of technical mechanisms such as connectivity platforms, APIs and SDKs, through working together with intermediary parties that create modular interfaces with complementors, and through the use of social mechanisms such as incentives	Making it easier to develop complements stimulates mobility in complementary assets, thereby increasing competition in these assets	A decrease in the value of these complementary assets, relative to the assets where the FF is active, which in turn creates an architectural advantageous position for the FF
DP2	In parts of a market architecture where the FF is active	The FF should restrict mobility by strengthening the appropriability regimes	Through an increase in barriers of entry and a decrease in competition	The value of these assets increases, relative to complementary assets in which the FF is not active, which creates an architectural advantageous position for the FF
DP3	For those components in which the FF is not active, and which do hold strategic value	The FF should focus on weakening the appropriability regime for these components by developing them and making (parts of) them publicly available	Since the public availability of such components will weaken their strategic value	Which will increase the relative strategic value of the components that the FF does hold.
DP4	In attracting developers of complements for a layered modular architecture, especially in the early phase of a market	The FF should aim for complements that require investments that are relatively high in fungibility	As, through a reduction of the fear of being locked in	This would make complementors more eager to participate
DP5	For those complement developers that are already tied into the layered modular architecture	The FF should aim to let these complements be supermodular or unique	As this will make participants more eager to make the combined product succeed	Thereby increasing the potential value of the layered modular architecture and its complements
DP6	In the initial phase of a platform market	The FF should aim to attract interested third-party complementors, build larger networks of interested parties, and build in-house complements	As this creates more innovative activity, reduces uncertainties related to the platform, opens up the opportunities for knowledge spillovers, creates incentives to innovate through competition, and creates incentives to help each other in generating business	Which would then lead to a higher quality and variety of components, and a higher value of the platform
DP7	When following a component strategy, or a bottleneck strategy in a crowded bottleneck	The FF should focus on collaboration, specifically on co-creating value with complementors, and on innovation in both its collaborative aspects and its components	As this will let the FF be able to have access to complementary components, to improve its own services, to differentiate itself from other component competitors, and to reduce investment risk	Which will allow the FF to create and appropriate more value
DP8	In the initial phase of a generative technology in a layered modular architecture	The FF should exert dynamic control, by influencing and monitoring its environment, by employing mechanisms such as roadmapping and showing successful examples, and by updating its strategies	Since through an increased ability to commit resources to the right applications, to gain control over bottlenecks, and to make sure partners also keep committing to the right applications	The FF will be more able to create and appropriate value
DP9	In the phase where actors focus on letting a new market emerge, and where dominant players from different industries are involved	The FF should not attempt to dominate the market architecture but instead focus on developing a market which is beneficial to all dominant players	As this would prevent the vicious cycle of resource allocation deferment from occurring	Thereby giving a market a chance to emerge
DP10	When innovation strongly depend on current sociotechnical systems, and these sociotechnical systems in turn are considered stable	The FF should engage in controllable innovation by focusing firstly on improving existing environments, engaging in combinatorial innovation, and by innovating in controlled environments	Since through decreasing the complexity of innovation	This makes successful innovation more achievable

These design principles can be summarized in some solution directions. First of all, operators should focus on building modularity into its network. This can be done in multiple ways, such as through building certain 5G capabilities (e.g. network slicing) into its network, through developing APIs and SDKs, and through developing connectivity platforms. In creating this technical modularity, the operator enables complements to be more easily developed based on its network, thereby stimulating complementary activity. Furthermore, it was also found that operators can collaborate with intermediary actors, who specialize in integrating the network of an operator with the complementary services. As such, these intermediary actors are then in fact responsible for creating modularity in the system.

A second solution direction, would be to adjust the appropriability regimes of the market architectures. Firstly, operators already engage in strengthening appropriability regimes, by acquiring spectrum through the national spectrum auctions. In many countries, operators are only allowed to deploy a network when they have acquired government-owned spectrum. The costs of acquiring the necessary spectrum bands can be enormous (Rijksoverheid, 2019). Secondly, some ideas were generated on how the telecom industry as a whole, might ensure that the appropriability regimes for assets that lie outside the telecom industry, are weakened, which would make the position of the telecom industry stronger. When one takes as an example, the automation of airport processes. Then, what would typically be needed, are super connectivity (5G), sensors (IoT), and AI. Now, when one assumes that for most airports the processes are relatively similar, then one might also assume that the underlying AI algorithms share similarities. If the latter is the case, then the telecom sector (e.g. in consortia forms), might focus its attention on creating such AI algorithms themselves, and bringing these then in packages freely on the market, publicly available. If this indeed is a feasible solution, then the strategic value of AI in airport settings would drastically decrease, which increases the relative strategic value of 5G connectivity.

The third solution direction entails attracting partner organizations, and collaborating with complement providers. Operators should focus on attracting partner organizations, firstly because this can stimulate the amount of complementary activity. Furthermore, building large networks of partners, allows for positive reciprocal effects, as partners can recommend each other to the organizations they are involved with, as such helping each other in stimulating business. Furthermore, collaboration between operators and complementors should evolve to one in which principles of co-creation are adopted. That is, services should be fully based on customer needs, which requires new ways of communicating with customers and therefore with complementors. Also, this way of collaborating allows operators to decrease risk in investments, by ensuring that investments will actually be used for intended purposes.

The fourth solution direction argues that operators should focus on innovation settings which are reasonably controllable. What this means is that when engaging in innovation efforts, operators should take into account which dependencies are at play, and how the existing sociotechnical regimes govern these efforts. For instance, when a factory has just recently adopted a connectivity solution based on Wi-Fi, the chances are rather low that the organization owning the factory is willing to change to a 5G solution. The implication of this practice-based design solution, is that operators should focus their attention firstly on connecting with those complementors, who focus on automating existing environments and processes. Furthermore, operators should refrain from those complementors who wish to develop very radical and extensive innovations, requiring many changes to existing systems. Instead, it is advised that operators focus on connecting with those, who aim to engage in combinatorial innovation, by taking use of existing systems, and changing these one step at a time. Closely relating to this, is the research-based design principle which argues that operators should only engage with complementors who develop complements that are relatively highly fungible. That is, investments that are highly specific pose a risk of failure, for the complementor and therefore indirectly for the operator. When failure then does occur, these investments can often not be redeployed. Instead, when investing in less specific complements, investments can, even in the event of failure, often be redeployed more easily, and as such the risk is much lower. This is especially important in the early phase of market emergence, as uncertainty and risk are then already that high.

Finally, the fifth solution direction on how operators should strategically act, argues that operators should exert dynamic control. That is, through influencing, monitoring and updating, operators can deal with the different types of dynamics and uncertainties, that are so present in the initial phase of markets based on nongeneric complements, in layered modular technical architectures. Specifically, empirical research uncovered that popular mechanisms, through which this can be done, are roadmapping and showing successful examples.

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1. Introduction

We are at the dawn of a new mobile infrastructure era, which is that of 5G. The combination of high speed, low latency and reliability, and the potential for carrying huge amounts of simultaneous connections, sets the stage for a digital revolution, by allowing for the creation of a vast array of new value propositions (Deloitte, 2018a; McKinsey, 2018a). This simultaneously creates a host of new challenges. Specifically, the telecom operator finds itself in a tough spot, with uncertainty about how to move forward. This thesis research will focus on designing a strategy for the Dutch operator, in settings of 5G-related business innovation.

1.1 General introduction

The functionalities which 5G offers, are a vast increase in speed, ultra-low latency, high reliability, more bandwidth, more lanes in the network, and increased efficiency in data transmission, and in energy (Deloitte, 2018a; Bain, 2018; Andrews et al., 2014). These functionalities, in turn have various implications for the business cases which can be delivered, in both the near-term, and the future. In general, applications for 5G broadly relate to three categories, which are IoT, or massive machine-type communication (mMTC), Mission-critical control, or ultra-reliable, low-latency communication (URLLC), and enhanced mobile broadband (eMBB) (McKinsey, 2018a; BCG, 2018). For IoT, in the future an enormous number of devices will have to be connected. One can, for example, imagine a smart city in which sensors and actuators are used for all sorts of applications. This category typically requires a vast amount of connections, at low power, and depending on the case, with low latency and constant low-bandwidth connectivity. URLLC applications, are applications which require total reliability. Examples are medical applications such as remote surgery, or applications related to safety, such as the autonomous vehicle, or applications relating to industrial automation. Apart from needing reliable connections, applications in these categories will also need to be able to respond instantaneously, which is why they need low latency. Thirdly, the category of eMBB contains applications which require higher speed, low latency, and more capacity. Applications fitting in this category are ultra-high-definition video, augmented and virtual reality (VR), and cloud gaming. Figure 1 depicts these use cases. Based on these application groups, it should also be noted, that there will be a change in the source of value. That is, historically the consumer is what generates value for the telecom operator. However, with 5G, it is expected that much new value will come from the business sector. This is also the focus of this thesis.

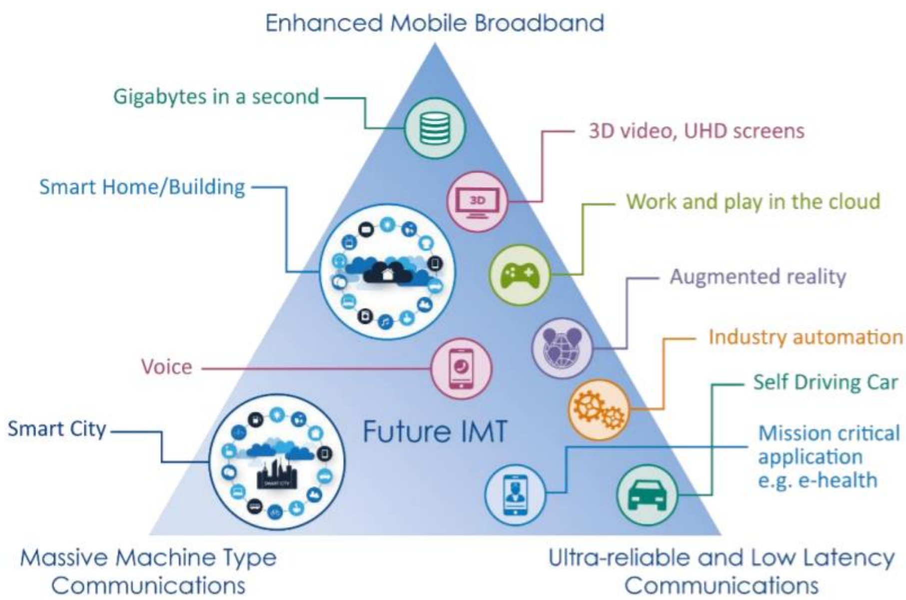

Figure 1: Use cases for 5G

Costs and barriers

Despite promising technologies, and revolutionary use cases, there are also numerous uncertainties around the transition to 5G. First of all, building 5G networks, or upgrading current networks to 5G, will require huge investments in the infrastructures (Deloitte, 2018a). Due to necessary investments in densification, spectrum acquisition, investments in deep fiber, and so on, the expectations are that the capital expense to sales ratio will go up for telecommunication operators (McKinsey, 2019a). Furthermore, it remains yet uncertain who will reap the benefits of these costs: the operators, or other parties, such as service providers (McKinsey, 2018a, 2019b, 2019c). This is in part due to the fact that operators are struggling in monetizing traffic growth, because of unlimited data plans (BCG, 2018). Even more so, operators have been experiencing declining revenues since the introduction of 4G (McKinsey, 2018b). For this reason, network operators are still hesitant in dedicating large investments to 5G.

However, somewhat opposing this view of significant costs, Bain (2018) argues that a number of factors are ignored. For example, 5G does not have to be deployed nationwide, but instead can be deployed in specific areas with high needs for the next generation of mobile technology. Furthermore, upgrading to 5G will generate spill-over benefits, such as capacity of 4G networks being freed up. In the same vein, BCG (2018) argues that absolute spending will increase, as more network capacity is needed anyway, to cope with increasing traffic demands. As a matter of fact, costs will be lower in the scenario of upgrading to 5G, than in the scenario of increasing 4G capacity, since 5G technology will be more data and power efficient (BCG, 2018).

Another barrier relates to cell site densification. Adding small cells, will require adding installations on street furniture, such as lampposts. Getting access to such furniture, which is often owned by municipalities, can be a major barrier however, due to radio-emissions constraints or building constraints (McKinsey, 2019b), due to urban disruption and visual pollution (McKinsey, 2018c), or simply because it can be a long, bureaucratic process (BCG, 2018).

Finally, the introduction of 5G can be seen as a trajectory in which the full engagement of all stakeholders is needed (BCG, 2018). Operators, governments and governmental organizations, municipalities, tower companies, content and service providers, technology vendors, and users, will all play a crucial role. Furthermore, organizations acting in a 5G environment, will typically have to invest in automation and integration technologies, and in security, which will require significant investments (IBM, 2019).

Roles

As stated, there is a multiplicity of different stakeholders involved in the trajectories around 5G, all with different roles to play. Starting with the telecommunication operators, these organizations are finding themselves in a difficult spot. As discussed, they will need to come up with huge investments into their networks, whereas the business case, and whether operators will derive significant value from those business cases, is still very uncertain. Added to that, with 5G it will become possible that devices connect to networks from different service providers, which could effectively mean that operators can lose their link with the consumer (Deloitte, 2018a).

A second category of stakeholders are governments, or policymakers and regulators. These stakeholders can help stimulating investments in 5G. This can for example be done by incentivizing investments in the deployment of networks, and investments in technological development (BCG, 2018). Furthermore, past and current policies often focus on increasing competition, as to decrease consumer prices. However, these policies decrease revenue for telecommunication operators, which will weaken their position to invest in 5G deployment. Similarly, the auctions of spectrum hosted by governments, result in huge investments for operators, which logically means less investments are available for 5G. Governmental organizations can also facilitate investments, by allowing operators to share network costs, by providing access to site locations for macro- and microcells, and by facilitating the procedures around receiving such access (BCG, 2018). Finally, governmental organizations can help investments in 5G, by actively implementing the technology for public applications.

When discussing governments, it is important for this research, to take into account the European context. In general, it is believed that Europe lags behind the US and China (Deloitte, 2018a; BCG, 2018). The policies mentioned above, which have focused on increasing competition, have especially been salient in Europe (McKinsey, 2019b). As a result, telecommunication operators in Europe have less finances available for investing in new 5G infrastructures, compared to operators in the US and China. Other factors which play a role in Europe’s lag, are the slower economic growth which Europe has been experiencing, its fragmented and small markets (McKinsey, 2019a), and the fact that Europe, unlike the US and the Asia-Pacific, does not house global digital leaders (BCG, 2018). Despite this disadvantageous position, it will be very important for Europe to successfully invest in 5G, as technological leadership will generate economic competitiveness, which was also found by a study for the European Commission. Furthermore, in this day and age, national cyber security is a crucial topic, which has generated active discussions across Europe as to who are trusted with 5G deployment.

Other stakeholders which are involved, are content and service providers, handset manufacturers, and technology vendors (BCG, 2018). Content and service providers will be enabled by 5G to create more value. Having generated significant revenues, these actors could actively try to cooperate and partner with operators, who have been less lucky in their revenues over the past years, in order to stimulate the development of innovative services. Handset manufacturers will be required in developing new devices, which will have to be 5G-ready. For technology vendors, it will be important to collaborate with operators as well, in order to develop 5G equipment, best suited to the needs of the operators. Generally speaking, developing and deploying 5G will require a coordinated effort of all these involved parties.

1.2 Problem definition

From the previous section, it can be concluded that the most important problems relate to uncertainty about how operators should strategically behave. There are multiple signals, about both opportunities and threats. Operators will need to make significant investments, yet it is uncertain if they will reap the benefits. Simultaneously, all the important actors must move in the desired directions, which poses another uncertainty.

Concluding from this, the problem can be defined as follows:

"The Dutch telecom operator experiences problems in strategically preparing for 5G-related business innovation."

1.3 Research questions

Following from the problem definition, this research will aim to uncover how Dutch telecom operators can strategically behave in the context of 5G-related business innovation. This then logically translates to the following central research question:

"How should telecom operators strategically behave in the context of 5G-related business innovations, in the Dutch market?"

This central research question can structurally be divided in the following sub-questions:

> SQ1: How can the context of 5G-related business innovations in the Dutch market, best be characterized?
>
> SQ2: How should telecom operators strategically act in that context?

1.4 Thesis setup

This thesis is built up as follows. Chapter 2 will describe the methodology which is employed in this thesis. Chapter 3 will focus on outlining the theoretical context that is found in this thesis, and on providing theory-based design principles. Chapter 4 will then provide an analysis of the results, which includes analyzing the context, the theory-based design principles, and deriving practice-based design principles. Finally, Chapter 5 will conclude on this thesis, and discuss the results, the practical and theoretical implications, and the limitations and avenues for future research.

2. Methodology

The aim of this thesis is to design a strategy that will allow operators to create and capture value based on the business innovations relating to 5G technology. This means that this thesis is in essence a design thesis, aiming to solve a real-world business problem. The notion of changing existing situations into preferred ones, is one that is central to the science of design (Simon, 1996). As such, it was decided to foremostly follow the principles of the science-based design approach, in which knowledge is used to create a desired situation.

A science-based design approach aims to generate prescriptive knowledge, in the form of solution concepts that prescribe what an actor should do in a given situation (Van Aken, Berends, Van der Bij, 2006). This prescriptive knowledge can be based both on what the theory prescribes in a specific situation, and on what is found in practice (Van Aken and Romme, 2012). The general approach that this thesis aimed for, was to develop a strategy design that is grounded both in theory and in practice, thereby adhering predominantly to the principles set out by Van Burg, Romme, Gilsing and Reymen (2008). The design principles that are developed, are formulated according to the CIMO-logic (Context, Intervention, Mechanism, Outcome) as specified by Denyer, Tranfield and Van Aken (2008).

An important factor to take into account regarding the approach to take, is the nature of the problem space (e.g. Van Aken et al., 2006). In this thesis, the focus is on the strategic context, specifically on that of the technical architectures and relating market architectures of 5G business innovations. As such, there is a relatively high degree of complexity and ambiguity in describing the context. Therefore, describing the problem and the context, also known as the problem space, became a central focus of this thesis. In doing this, iterations were continuously made, with results from empirical and theoretical research, and from the developed design principles, being used to refine the problem space.

Furthermore, in order to describe both the technical- and market elements of business innovations relating to 5G, explorative research is needed. For this reason, this thesis resorted mostly to qualitative methods in gathering and analyzing data. After an initial outlining of the context, a literature review is conducted to further characterize the context, and develop design principles. Simultaneously, a case study is conducted, in which the case of interest is the Dutch telecom operator creating and appropriating value from 5G-related business innovations. For this case study, interviews are the dominant form through which data is gathered. Additionally, documents from industry actors and field notes are used. Field notes were created when engaging with industry experts, and when attending several sessions with key industry actors. The adopted principles for these research activities, largely overlapped with the case study roadmap that has been proposed by Eisenhardt (1989). As will be described in the data collection and analysis part (section 2.2), the data gathered very much shaped the research process, with many iterations before the research settled on a definitive context, definitive constructs and definitive design principles. Furthermore, in the case study, theoretical sampling was applied, and multiple data collection methods were employed.

The overall logic leading the process of formulating theoretical constructs, and of data gathering and analysis, can be mostly characterized as an abductive one (Morgan, 2007; Eisenhardt, 1989). That is, through an initial set of interviews and scan of industry documents, some initial inductions were made as to which theoretical concepts best resembled this context. This was then followed through deduction based on the multiple data sources. Similarly, the interviews used for the case study, were first inductively analyzed through applying the Gioia methodology (Gioia, Corley, Hamilton, 2013). Then, the formed categories were compared with the theoretical ones, allowing for deducting both the context and design principles.

2.1 Research approach

As stated in the previous section, this thesis adopts a science-based design, aiming to develop prescriptive knowledge that is both grounded in theory and practice. Furthermore, some other important elements were mentioned, such as the overall logic being that of abduction, and developing a design according to the principles of Van Burg et al. (2008) and Denyer et al. (2008). This section aims to detail the adopted research approach, which is schematically shown in Figure 2.

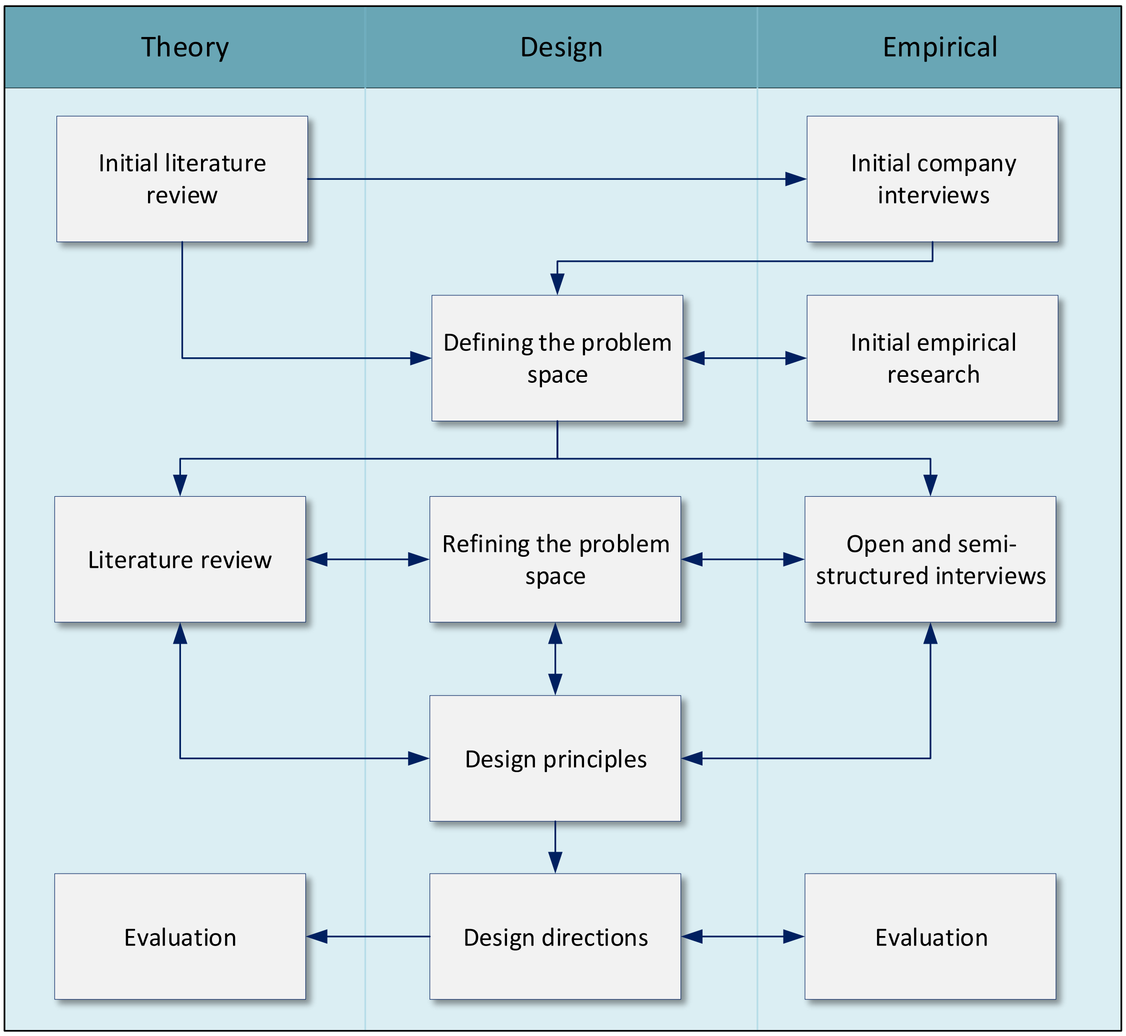

Figure 2: Research approach

This research started off with a broad literature review on the concept of innovation ecosystems, which created a list of ecosystem related challenges and mechanisms to deal with those challenges. The initial purpose of this research, was to see if the innovation ecosystem concept could be of benefit to the innovation context of Strict or its clients. Therefore, the initial company interviews were guided by some of the results of the initial literature review, for instance by delving into some of the dependencies typically found in ecosystems. The results of these two activities made up the input of a first demarcation of the problem and related context. Multiple interesting problems were identified, and it was decided to focus on the context of 5G-related innovation. Following this decision, more data needed to be gathered, in order to make a valid initial sketch of the context, and to more specifically determine on which avenue within 5G-related innovation to focus. To this extent, documents from the telecom industry were gathered, which delved into the general characteristics of 5G technology, the benefits, challenges, players, and so on. These documents were analyzed, and led to a refinement of the problem space. Based on this added context, it was decided to focus on the perceived challenge for operators to prepare for 5G-related value creation and appropriation, and to create a design which would allow them to do so.

After this initial phase, it was decided, for multiple reasons, to first focus on elaborating on the context. As stated before, already at this stage there was a high degree of perceived complexity and ambiguity. There were many potential actors, many challenges, uncertainties relating to which value propositions based on 5G are going to be successful, and so on. Also, most documents that were used, did not focus on the Dutch context specifically, but rather on an aggregate of Western markets (EU- and US-based), or on markets from neighboring countries. Therefore, open and semi-structured interviews were held with a diverse set of actors who are currently involved in 5G-related innovation, with the goal of addressing how the context of 5G is perceived in The Netherlands, and how operators should strategically act in that environment. Furthermore, at the start of this phase, a reflection on the innovation ecosystem literature was done with the second assessor from the university. In this session, it was determined that the literature that had been used so far, did not best reflect the context as it was perceived at that time. In this session the most important theoretical constructs relating to the context, as it was perceived at that time, were discussed, and based on that the second assessor recommended a set of academic papers which reflected those constructs. These papers were then used for a second literature review.

Both the literature review, and the open and semi-structured interviews, were conducted in tandem, over a prolonged period of time. That is, this was an attempt to not knowing the relevant theoretical literature in too much detail, thereby adhering to the principle of a ‘clean theoretical slate’ (Eisenhardt, 1989; Gioia et al., 2013). Continuing over time, the results from these activities informed each other, through a refinement of the context. So, interviews that were held in a later stage were based on an advanced understanding of the context, due to earlier interviews and literature research.

After some time, while still being in the stage of doing interviews and studying the literature, design principles were formed. These design principles not only served as an input to the design itself, but also acted as boundary objects such as described by Romme and Endenburg (2006). That is, these design principles connected the theoretical constructs put forth by the academic world, with the way in which actors in the empirical world perceive their world. Design principles identified by literature guided some of the topics discussed in interviews, and in other instances design principles allowed for a reinterpretation of the data from the interviews. Similarly, design principles were used as input for additional literature.

When the context was deemed to be sufficiently established, a final set of design principles was created based on both theory and practice. These principles were the input for several design directions. That is, this thesis never aimed to develop a definite strategic design for operators, as the telecom world is a technologically complex one with many specific contextual requirements. Rather, this thesis aimed to develop the overall directions in which Dutch operators should search to create their own successful strategies. Finally, these directions were evaluated by placing them in the light of theory, and by discussing them with some experts of the telecom market. The discussions were also used to improve upon the design directions.

Overall, the chosen approach can be characterized as continuous iterations of contextualization and decontextualization, as described by Van Burg et al. (2008). Decontextualization happens through taking the empirical context, and placing it in the theoretical domain. That is, through inductive reasoning, general theoretical constructs are identified which characterize the operator's context and the emergent design that operators use in that context. The other way around, contextualization takes general (i.e. decontextualized) theoretical constructs, and places these into the specific context of interest. This happens for instance, when theory-based design rules are placed into the specific context of an operator.

2.2 Data collection and analysis

In order to describe both the context of the operator regarding 5G-related business innovation, and the strategic behavior necessary in that context, both empirical and theoretical data was gathered and analyzed. Though it should be noted again that the empirical and theoretical activities were done in tandem, shaping each other through multiple iterations, this section will describe the data collection and analysis methods for them separately.

2.2.1 Theory

As stated previously, one of the inputs for this research was a literature review that delved into the innovation ecosystem concept. This literature review gave a broad overview of what the innovation ecosystem concept is, which challenges it should theoretically deal with, and which mechanisms it proposes to deal with those challenges. In the end, the results of this literature review did not influence the design and the context analysis itself, which is why this section will not detail the methods used for that review. However, the initial literature review did influence the selection of papers for the second literature.

In a session with the second assessor on the ecosystem literature, a set of papers was provided, that deal with those concepts that were deemed to be of high importance in the context of this thesis, and that were deemed to be theoretically interesting, as these topics received little attention in the innovation ecosystem literature. This set of papers, alongside the theoretical constructs that were of interest, are listed in Table 1.

Paper title	Authors	Theoretical constructs of interest
Building the value of next-generation platforms: the paradox of diminishing returns. (2018)	Carmelo Cennamo	• Complement quality and variety • Platform competition • Dynamic relation between amount of complementor activity and the quality and variety of complements
Maneuvering in poor visibility: how firms play the ecosystem game when uncertainty is high. (2018)	Brice Dattée Oliver Alexy Erkko Autio	• Generative technologies • Uncertainty • Ecosystem dynamics • Value creation and value capture

How firms navigate cooperation and competition in nascent ecosystems. (2018)	Douglas P. Hannah Kathleen M. Eisenhardt	• Ecosystem strategy • Competition and cooperation dynamics • Bottleneck dynamics
Towards a theory of ecosystems. (2016)	Michael G. Jacobides Carmelo Cennamo Annabelle Gawer	• Ecosystem emergence • Modularity • Complementarity
The market that never was: turf wars and failed alliances in mobile payments. (2015)	Pinar Ozcan Filipe M. Santos	• Market emergence • Market failure • Market architecture
Two-sided network effects: a theory of information product design. (2005)	Geoffrey G. Parker Marshall W. van Alstyne	• Multi-sided markets • Strategic complements • Pricing strategy

Table 1: Recommended paper selection

In the process that followed, these papers were analyzed and used to refine the context and inform theory-based design principles. This was done by analyzing the papers mentioned in Table 1 according to listed theoretical constructs of interest. As mentioned before, this was also done simultaneously with the gathering and analysis of empirical data, and as such these two parts informed each other. For instance, from the initial empirical research it was concluded that an important characteristic of 5G technology, is its potential for enabling the creation of a large variety of new value propositions. One of the recommended papers, that of Dattée et al. (2018), describes this character trait as generativity, with generativity typically following from the architecture of a technology. This notion informed empirical research, by gathering more data on the architectures of 5G networks. Furthermore, through snowballing, the notion of generativity also led to the use of extra literature, specifically that which focuses on the product architectures that allow for generativity. Through this process of gaining an advanced understanding of the context by empirical and theoretical data, several theoretical constructs were identified that warranted the use of new academic literature.

The theoretical constructs that represented the context of this thesis, were logically divided into groups. The first group that is dealt with is that of generativity, simply because it is argued that in the empirical environment, 5G is a generative technology, and because the notion of generativity serves as a good introduction for the following groups. The second group deals with architectures, which is subdivided into technical- and market architectures. The technical architecture contains theoretical constructs such as modularity, product components, and functional layers. The market architecture contains constructs such as complementarity, again modularity, cognitive and structural market elements, and multi-sided markets. The third group deals with uncertainty, which lists the types of uncertainty that are typical for the type of market- and technical architectures that this thesis deals with. The fourth group does the same for the types of dynamics that can be found in this context.

Overall, the papers used to analyze the context of this thesis were mostly acquired through a recommendation of the second assessor and through a process of snowballing. That is, based on an advanced understanding of the context, the references of papers listed in Table 1 were checked according to the theoretical constructs that warranted extra research. Finally, on a few occasions, knowledge from the initial literature review, and from previous university courses, was used to clarify some theoretical constructs that were deemed important.

2.2.2 Empirical research

In this research, empirical data was mostly gathered through open- and semi-structured interviews, and through documents. Furthermore, some sessions with important actors from the industry were attended, where data was gathered through taking field notes. The empirical data was mostly gathered and analyzed according to the principles for case study research by Eisenhardt (1989) and the principles of Gioia et al. (2013). In other words, this thesis research resorted to qualitive methods for gathering and analyzing data, which is something that is fitting in a context which warrants exploration (Yin, 2015).

Initial interviews and business literature

As stated before, the input for this research was a literature review on the innovation ecosystem literature. To start this thesis research off, both initial company interviews and a small study on business literature relating to the ecosystem concept were conducted. For the purpose of the latter study, articles and whitepapers from the business world were gathered that dealt with the topic of ecosystems and digital innovation (i.e. Strict's focus is on digital innovation), and these documents were analyzed in terms of the trends which related to those topics. This led to the creation of a cause-and-effect diagram which summarizes why the ecosystem concept is relevant in the business world. This figure is of no particular interest to the results of this thesis, yet for the sake of completeness in arguing how methods were chosen, it is included in Appendix A.

For the initial interviews, open- and semi-structured interviews were used. The initial company interviews, served to establish how the innovation processes at Strict and at Strict's clients went. In total 9 initial interviews were conducted, of which 7 were done with employees of Strict, and 2 with clients. The interviewees were selected based on the input of the company supervisor, who came up with a list of employees who might have had interesting insights regarding innovation. A list of the interviewees for the initial interviews, and their most important characteristics, can be found in Appendix B.

For the initial interviews, topics were identified which were to be covered during these interviews. That is, the goal was to uncover the innovation processes of Strict, and potential problems relating to these innovation processes. Furthermore, talking points were also based on the literature review of the innovation ecosystem concept. Finally, at this stage a potential intention of this thesis, was to do research on a specific tool that has been developed by one of the university supervisors. That is, the initial literature review, initial company conversations and the small study of business literature indicated that some relevant problems related to managing the dependencies, that are found in many current innovation tracks. In turn, the specific tool deals with some of these relating challenges in creating innovation ecosystems. For this reason, this tool was introduced to the interviewees, asking for their opinions on it, and whether it would help them with some of the problems that they identified. The nature of these interviews were mostly open-ended. That is, even though talking points were identified, it was deemed most important to uncover what the interviewees felt was important relating to innovation.

The first 6 interviews were transcribed and analyzed inductively according to the Gioia methodology (Gioia et al., 2013), in NVivo. As these interviews were only initial ones, this was done in a rapid manner. That is, the interview transcripts were read once, and individual codes were created based on what interviewees had stated relating to innovation. After having done this for 3 interviews, categories were formed in which the individual codes were placed. Following that, the other 3 interviews were again read and coded. The individual codes from these interviews were then placed either in existing categories or in new categories. Codes and categories were also compared, resulting in the merging and altering of some codes and categories. This process was relatively simple, as codes only served to create a general description of the innovation processes and relating problems. The innovation problems were also schematically represented in cause-and-effect diagrams. These diagrams are of no further relevance to this research, yet, again for the sake of completeness in the argumentation of decisions made, they are included in Appendix C and D. After having created this narrative of the innovation context of Strict, the results were discussed with the two company supervisors individually. As it was felt that a point of saturation was reached, it was decided that the remainder of the interviews would be used solely for validation purposes. Therefore, the interviews were relistened rather than transcribed, notes were taken and compared with the narrative, and it was indeed concluded that no further analysis was needed.

Initial empirical research on 5G

At this point, the decision was made on which problem to focus. In conversations with supervisors and people at the company, it was felt that though the innovation ecosystem concept was interesting and that though the introduced tool could be applied to some innovation trajectories at client companies, that a project in which this tool was tested at other companies could be impractical. That is, large amounts of time would be required of clients who were not directly responsible for this thesis, and innovation cases would need to be identified based on these being in the formation stage, and on dependencies playing an important role. As such, an extensive search process would be required, possibly requiring some convincing, and therefore having uncertain outcomes. Simultaneously, talks within the company raised 5G as an interesting topic for this thesis research. That is, some interviewees had expressed their concerns for Strict's ability to prepare for the future. 5G was also mentioned as one of the technological trends which had the ability to profoundly change the business world in which Strict is embedded. Thirdly, 5G was seen as a topic relevant to the ecosystem literature, as innovations based on 5G were seen as likely to contain many dependencies, and since small 5G-related innovation ecosystems were being created. For these reasons, it was indeed decided to focus this thesis research on 5G.

After this decision, initial empirical research on the context of 5G was done. This was mainly done by consulting documents from the industry. These documents were whitepapers, reports, articles, videos, and so on, mainly from big consultancy agencies, and technology companies. Additionally, some scientific papers were used which elaborated on the characteristics of 5G. These documents were all analyzed, by writing summaries, and then subsequently coding these summaries inductively in NVivo. This resulted in an initial description of what 5G technology exactly was and what it offered, what kinds of value propositions it would make possible, who were the most important players, if there were any particular drawbacks, and so on. These findings were complemented with some conversations with people from Strict. Based on the image that was emerging, the decision was made to focus on the strategic challenges that the telecom operator would face in generating and appropriating value from 5G related business innovations. This context was deemed as most interesting, because the telecom operator is a crucial actor in getting 5G to the market, because Strict has close relations with the Dutch operators, which makes it interesting to Strict, and because it appeared that operators find themselves in a challenging position. Finally, this decision was made because it appeared that much of the promised value would follow from value created in a business setting, which is a new situation for the typical operator.

Main interviews

Data collection – Now that the problem space had been reasonably defined, the main part of the research followed. This part of the research was concerned with analyzing the context, and developing a design based on that context. A case study was conducted here, with the aim of researching how operators currently act, and how they should act, in order to create and appropriate value from 5G-related business innovation. The main part of the data was acquired through interviews. The interviews here basically served two purposes. On the hand, they served to describe how the operator currently acts, or how they should act, in the case under study. This therefore serves to inform the practice-based design principles. On the other hand, interviews also served to delve deeper into the context. A better understanding of the context would then logically lead to better informed research-based principles. The implication is, that not only the perspective of the operator, or those close to the operator, is needed, but rather a set of perspectives from diverse actors who are all involved in 5G-related innovation. For this reason, it should be clear that in the selection of interviewees, theoretical sampling (Strauss and Corbin, 1990) was applied, as interviewees were chosen based on their knowledge of 5G business innovation in The Netherlands and/or their knowledge of the Dutch operator. This process of interviewee selection was also based on the advanced understanding of the context. That is, due to findings from literature and interviews, new interview candidates were identified. From this process of interviewee selection, a diverse set of interviewees emerged, of which a list with interviewee characteristics can be found in Appendix E. As indicated before, these interviews were carried out simultaneously with the literature review, and as such interviews were spread out over a longer period, as can also be seen in Appendix E. Interviews lasted between 35 and 125 minutes, with an average time of 56 minutes. It should also be noted that there are two special cases for these interviews. The first is that interviewee 1 was interviewed twice. The first interview was done as part of the initial interviews, though this interview has been used as well for the main analysis. That is, this particular person had made relevant statements in the initial interview, regarding both operators and 5G, which added to the analysis. The second interview with this person was a 2 hour-long interview/session. The reason for this length, was that apart from dealing with the topic of 5G, this interviewee explained, and graphically sketched, the current architecture of an operator. The second special case is that interviewee 20 and 21 were interviewed together, in one interview. The particular organization suggested to conduct the interview with those two individuals rather than just one, because it was argued these two individuals complemented each other’s knowledge.

The interviewees listed in the table in Appendix E, were all identified through direct and indirect relations of Strict employees. Most of these were contacted through employees of Strict, and when they expressed their interest to participate in this thesis research, I subsequently contacted them to make an appointment, explain to them the purpose of the research and the format of the interview, and to ask them for their consent to be audio recorded so that interviews could be transcribed. Prior to each interview, the purpose and format were again repeated, and permission was again asked to audio record the interview. The topics and questions of the interviews were based on findings from the main literature review, the initial empirical research, and findings from the interviews themselves. In the interviews, some of the techniques proposed by Eisenhardt (1989) were adopted. The interview guide, with questions and techniques employed, can be found in Appendix F. After an interview was conducted, almost all interviews were transcribed within 48 hours. The transcribed interviews can be found in a separate Appendix, due to confidentiality reasons.

Data analysis – Interviews were extensively analyzed according to the Gioia methodology (Gioia et al., 2013). All interviews were transcribed and analyzed in NVivo. For each individual interview, the transcripts were read first. After this, interviews were then coded through a first-order analysis. Codes were based on what interviewees had said. Since in the early analysis it was about coding that which interviewees deemed important, rather than immediately tying interviews to predefined categories, many codes would be generated per interview. After the first-order analysis had been done for an individual interview, a graphical overview of relationships among the codes would be created. This was done to gain a better understanding of the data structure. An example of this can be found in Appendix G. After having done these first-order analyses and graphical representations of the data for 3 interviews, first attempts at the forming of second-order categories were made, according to what Strauss and Corbin (1990) call axial coding. This was done by comparing the generated codes and graphical narratives, and seeking for similarities. The process then continued by analyzing the next two interviews again through first-order analysis, and to then compare the newly generated codes with the created categories and former codes, which allowed for updating them step-by-step. This process was followed until all interviews were added to the analysis. Since interviews were done with a heterogeneous set of actors, and gave space for the interviewee to delve into what he/she deemed important, a large set with over 700 first-order codes was generated. This also resulted in quite a lot of categories, which not only described the context purely from the perspective of the operator, but also from the perspectives of other important actors. The key actors were grouped, and for each a large narrative detailing their particular characteristics was written. These were later not directly included in the diagnosis, but helped in forming a clearer image of the context in which the operator is located. After this had been done, all categories were compared with the literature that was used. Based on this comparison, a final set of categories with codes was created, characterizing the context of the operator, and how the operator should create and appropriate value in that context. These categories were, for the sake of overview, placed on tables according to their topic. It should be noted that the more detailed version of these table, which contains interviewee quotations, are provided in a separate appendix, due to confidentiality reasons.

Other data sources

Apart from the interviews, other data collection methods were also employed, which, through the triangulation of evidence, strengthens the analysis (Eisenhardt, 1989). Apart from the interviews, many unrecorded conversations were held with industry experts. These experts were mainly employees from Strict, but also purposeful conversations with individuals from operators, technology vendors, and those engaged in 5G programs were held. For instance, two telephone conversations were held with 5G program managers from two different municipalities. Also, multiple sessions were attended in which 5G-related topics were the central focus. For instance, two 3 hour-long sessions, with two of the big telecom technology vendors, were attended. In these conversations and sessions, field notes were taken. These added to the analysis, by guiding the search process, by making it easier to interpret data, and by an increase in reliability of the findings. For instance, in the mentioned sessions, technology vendors elaborated on which applications they saw as most important in the coming years. This data was then used as input to guide interviewees, by providing them with example applications, and examples of how some strategically viewed the market.

The most prominent alternative source of data came from documents from the industry. In this phase, documents were mostly used to add to the analysis of the technical architectures, and therefore came from technology companies and technology standardization bodies. This was done, because even though some respondents gave clear insights into the technology, it was judged that some insights into the technology were still lacking. Furthermore, the use of technology whitepapers were deemed the best way to examine the statements made by interviewees. Apart from these technology documents, also market-oriented data was consulted. These include documents and videos, on which applications are most promising, on which parties are developing propositions and what sorts of propositions, on which challenges are most important, and so on.

2.3 Design principles

The focus of this study was to create a set of design principles for a strategic design for operators, which are constructed according to the CIMO logic of Denyer et al. (2008). CIMO stands for Context, Intervention, Mechanism, and Outcome. The CIMO logic therefore implies that in a certain problem context, a specific intervention is suggested, which produces, through certain mechanisms, a desired outcome. This logic is useful, because it not only describes what will work in a given situation, but also aims to explain why something works, which increases the relevance of a design.

Design principle can be based both on theory and on practice, as is exemplified in both Van Aken and Romme (2012), and in Van Burg et al. (2008). This logic is also applied here. That is, the empirical data was analyzed to derive which emergent designs were being created by operators. Furthermore, based on an analysis of the context, literature was applied to create a deliberate, research-based design. Especially this latter aspect was iterative in nature. Initial empirical research, and the early findings of the main interviews, served as the basis for the literature review and the research-based design principles. The subsequent empirical research was then used to verify that the general contexts described in the literature were indeed similar to the context found in the empirical setting, thereby verifying the design principles. Furthermore, the subsequent empirical research was used to make the design principles more specific, applying them to the context of the operator. However, it should be stated that, though elements of emergent strategies were discernable, these were still too vague and incohesive to fully rely on them. What this means is, that for some of the principles it was difficult to contextualize them such that they were based both on practice and theory. As such, some of the principles were fully based on what research prescribed in a given context.

2.4 Validation

The validation of the design only constituted a relatively minor aspect of this thesis research. That is, validation, has been done through preliminary alpha-testing. Sessions and informal conversations with Strict employees were held to discuss the final set of design principles. In these sessions, the focus lay on validating whether the proposed principles were applicable in the context of the operator, whether they could indeed achieve desired results, and whether there were any specific requirements to take into account. However, I argue that most of the validation happened in the data analysis part of this thesis, through corroborating with empirical evidence, that it is indeed justified to equate the abstract context of the literature, with the specific context of this thesis. This direction was also chosen, since from interviews and conversations with people in the industry, it was concluded that most do not know which directions exactly an operator should take. Furthermore, all of the discussed applications of 5G-related business innovation have not been introduced in any markets yet. For these two reasons, it was difficult to field-test these design principles, and as such there was a strong reliance on corroborating that the academic context can indeed be equated with the empirical context.

3. Theoretical background

This chapter will deal with describing the context from a theoretical perspective, and the design principles that theory prescribes for that specific context. For this purpose, section 3.1 will describe generative technologies. Section 3.2 will then outline the technical- and market architectures that can be found in this context of generative technologies. Section 3.3 will provide a description of the types of uncertainty, and section 3.4 describes the dynamics found in this context. Finally, section 3.5 will describe how to create and appropriate value in the described context.

3.1 Generative technologies

In the introduction, 5G was labelled as a generation of new technologies with the potential to enable the creation of a large variety of new value propositions, which fits the description of generative technologies (Dattée et al., 2018). This is important, as the notion of generativity beckons the question as to which value propositions actors should commit resources. To begin to answer that question, the concept of generativity should be explored a bit further, to decide whether 5G will be a generative technology generation.

According to Zittrain (2006), there are four criteria that make a technology generative:

1. First, generative technologies have a high capacity for leverage. That is, generative technologies enable the creation of a variety of value propositions which would otherwise be impossible or too difficult to create.
2. Second, generative technologies are adaptable to a wide range of applications.
3. The third factor is ease of mastery, which denotes how easy it is to adopt and adapt a technology.
4. Fourth, the more accessible a technology is, the more generative it is. It also follows from this notion of accessibility, that the higher the costs incurred to use a technology, in terms of finances, acquiring information, dealing with regulations, and so on, the less generative a technology is.

Based on these four criteria, some nuance must be provided when arguing that 5G will be a generative technology. That is, despite the many potential applications for which 5G can be used, the introduction already identified some barriers to the deployment of 5G technology. Furthermore, despite the fact that in previous mobile generations, service providers have been fairly able to master mobile technologies, for example showcased by the huge number of mobile applications, it still remains uncertain whether this will be the case for 5G. That is, many of the applications mentioned, require the interplay of multiple complex technologies, such as AI and IoT, and will likely be developed by networks of actors, rather than by one content provider.

Having identified the potential uncertainty as to whether 5G will be fully generative in nature, the question then turns to what would make 5G a generative technology generation. According to Dattée et al. (2018), a typical instance of generativity occurs when technological changes are introduced at the lower layers of architectures. Based on the information provided in the introduction, this seemingly is also what will happen with the deployment of 5G. That is, introducing new technologies at the physical infrastructure (e.g. cell densification and massive MIMO) and at the digital infrastructure (e.g. MEC and network slicing), supposedly enables the creation of new applications at the service and content layers (5G PPP, 2019). Arguing that generativity follows from architectures, it makes sense to explore the concept of architectures and its relation to generativity and value creation, a bit more in depth, before answering the question as to how actors should strategically behave in the context of generative technologies.

3.2 Architectures

An architecture defines how a system functions. It specifies the components, the configuration of these components, and the relations among these components (Baldwin, 2015). As was discussed in the introduction, there are multiple architectures at play, dynamically relating to each other. First, there is the technical architecture, which defines how the designed or technical components must be created, and how these relate to each other (Baldwin, 2015). Second, the industry architecture (Jacobides, Knudsen, and Augier, 2006), or the market architecture (Ozcan and Santos, 2015), defines the roles and interdependencies of all involved actors in the process of value creation. Jacobides et al. (2006) argue that their definition of the concept of the industry architecture includes a technical architecture. While concurring with that statement, this thesis chooses to deliberately distinguish between a market architecture, along the reasoning of Ozcan and Santos (2015), and a technical architecture, for the purpose of making explicit the dynamic relationship between the economic reasoning of actors in the market, and the technical possibilities.

3.2.1 Technical architecture

Early research on product architectures distinguished between modular and integral architectures (Ulrich, 1995). Modular architectures decompose products into loosely coupled components, with standardized interfaces between those components. This reduces complexity of both the product and the design of other components (Baldwin and Clark, 2000). Integral architectures contrast modularity, by being characterized by complexity, non-standardized and tightly coupled interfaces between the components of a product (Ulrich, 1995). As Yoo, Henfridson, and Lyytinen (2010) describe, the literature on architectures has shown that these different typologies determine how organization should organize themselves, and how they should strategically behave.

Moreover, Yoo et al. (2010) argue that due to the use of digital technology in product architectures, a new typology of product architecture has emerged, which is called the layered modular architecture. There are two important characteristics of digital technology which lead to layered architectures. First of all, digital devices are reprogrammable, which means that due to the separation between the processing and storage of data, functional logic is separated from the physical component that executes a task. This means that device and service can be separated. Second, data is homogenized, which means that data from heterogeneous sources can be processed in a combined manner, because analog signals are mapped onto a set of binary numbers. The result is that networks and contents are separated.

The layered architecture that follows from digital technology consists of four layers, as illustrated in Figure 3. The device layer consists of the physical components present in a system, and a logical capability layer, such as an operating system, through which physical components can be controlled and connected to the other layers. The network layer determines how data flows from the device to the service logic. Therefore, it includes physical components used for transportation of data, such as fiber or radio spectrum, and it includes a logical layer which adds logical functionality that specifies how data is processed. The service layer consists of “application functionality that directly serves users as they create, manipulate, store, and consume contents” (Yoo et al., 2010, p. 727). The contents layer consists of the data being processed and created by the application functionality, such as videos or texts, and of metadata and directory information.

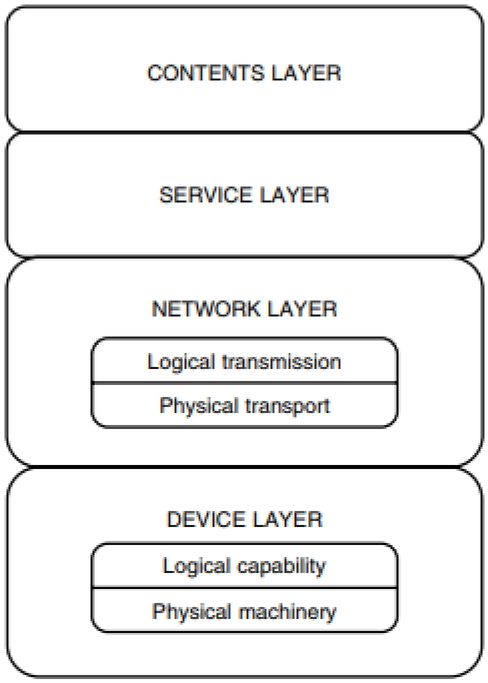

Figure 3: Layered architecture of digital technology (Yoo et al., 2010)

Yoo et al. (2010) argue that as more digital components are embedded into physical products, layered modular architectures emerge. Due to loose couplings, or standardized interfaces, between components and layers, it is fairly easy to combine different components from different layers. As such, when new innovations in a certain layer are introduced, there potentially are a vast amount of combinatorial possibilities for new product innovations. This is also where the generativity of layered modular architectures comes from. Simultaneously, because of this generativity, component designers cannot know ex ante for which products or value propositions their components will or can be used. An example given by Yoo et al. (2010), is how Google Maps can be both a standalone product, and be used as a component for many different kinds of products and services.

As such, the layered modular architecture clearly has profound impacts on how products are created and organized, and this is why Yoo et al. (2010) argue that this also changes the ways in which organizations must behave. They describe how the location in a layered modular architecture could impact a firm's choice between cooperation and competition. An example is how Apple and Amazon compete in the device layer of e-readers, with the iPad and the Kindle, but how they cooperate in the service layer, as Amazon provides applications for Apple's devices. In general, Yoo et al. (2010) argue that strategically acting in layered modular architectures is about stimulating complementary and heterogeneous activity in the layers outside the layer in which the focal firm is located.

3.2.2 Market architecture

Apart from the structure that defines how a technical system functions, there is also a structure which defines the roles in creating, delivering and appropriating value, which Ozcan and Santos (2015) label the market architecture. Markets and their architectures emerge because they "offer a viable mode of production and exchange for a set of economic agents" (Jacobides et al., 2006, p. 1203). When a market emerges, there logically are multiple possible architectures through which this production can be achieved. Following a process that can be characterized by both cognitive and structural elements, eventually a stable market architecture is formed (Ozcan and Santos, 2005). The cognitive elements relate to a process of economic actors recognizing an economic need, around which then a market can emerge. This cognitive process is characterized by high initial cognitive uncertainty about what exactly the product is, what the market is, which firms are involved in the creation process, and how these firms should work together. What then follows is a process of legitimation, in which eventually a market with specified products and roles crystallizes. The structural elements relate to the interactions of actors that lead to new structures around which markets are formed. This second view recognizes the patterns through which structures emerge. That is, typically a technological discontinuity is the starting point of a process in which actors explore possible innovations, which eventually leads to a dominant design (Suárez and Utterback, 1995).

Complementarity

The market architectures which can be distinguished in the context of a layered modular technical architecture, are composed of complementary components, together forming a product. Complementarity is the phenomenon, where two or more components, yield superior value in combination, as compared to when they would be produced or consumed in isolation (Jacobides et al., 2006). Jacobides, Cennamo and Gawer (2018), distinguish between generic, unique, and supermodular complements. The argument that they put forth, is that the type of complement, has differential impacts on how markets should be organized. Generic complements are those that are highly standardized, and easily acquirable on markets. Because of this, there are no specific coordination requirements for organizations in acquiring them.

Unique complements, are those complements which maximize the value of the system, or which are required for a system to function. Supermodular complements, are those complements for which an increase in their quantity leads to an increase in the value of the system. The latter two types of complements determine the superior value that can be realized, as the joined consumption of unique and supermodular complements creates more value than when they are consumed in isolation.

An illustrative example relating to 5G would be the different complements found in the potential case of autonomous driving. In this potential case, unique complements would be IoT and AI functionalities. If these functionalities are non-existent, then autonomous driving based on 5G communication would not be possible. Supermodular complements on the consumption side would be an increase in users. That is, the more autonomous cars that are on the road, the more data will be sent between cars, which would increase the quality of the service.

The crucial point that Jacobides et al. (2018) make, is that nongeneric components create a coordination need which cannot be addressed by some of the standard market forms. For example, mobile devices, operating systems, and mobile applications, can hardly be produced in isolation. Neither can consumers consume these components individually, since mobile applications only have value when consumed on a mobile phone with an operating system. So instead, a much more efficient variant would be to produce them in a coordinated effort across the individual producers.

Modularity

According to Jacobides et al. (2018), this coordination can be solved by means of modularity. That is, it was already established that modularity implies standardized interfaces between decoupled components. Modularity therefore allows for a division of labor, with interdependent components being developed by different actors. In this sense, modularity decreases the need for strict coordination by a central actor. Instead, complements can be created with a degree of freedom, as long as they adhere to the standardized interfaces. Because of this, modularity in the technical architecture is also what allows for these types of markets to emerge (Jacobides et al., 2018). The ensuing market architectures are graphically represented in Figure 4.

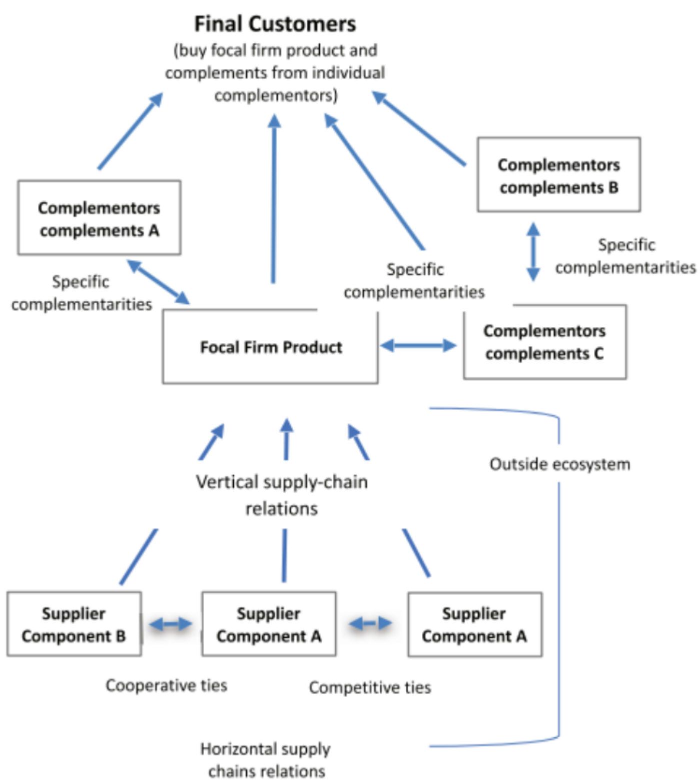

Figure 4: Modular market architecture for nongeneric complements (Jacobides et al., 2018)

Market interfaces

When eventually a stable market architecture has emerged, what in fact has been created is a relatively stable set of actors, and interfaces between those actors (Jacobides et al., 2006). These interfaces are what represents the division of labor in the creation of a product or a service. This in turn implies that these interfaces can be technological assets, standards, social mechanisms, and so on. It goes without saying, that modularity is a form of a market interface. The interfaces in a market architecture hold great importance, because they both drive and indicate the occurrence of co-specialization among the actors of a market. That is, the individual actors' offerings which together make up the product or service of a market, are designed in such a way, that the interactions among those individual actors are becoming increasingly efficient. The main implication is, that in markets in which interactions are highly efficient, the transaction costs among the co-specialized actors are minimized. This also explains why stable markets are often very difficult to change.

Bottlenecks

Within these layered modular architectures, consisting of complementary components, an important issue is which components hold the most strategic value. The components that do, are often called bottlenecks (e.g. Jacobides et al., 2006). Baldwin (2015) distinguishes two types of bottlenecks, technical and strategic. Technical bottlenecks are bottlenecks that can physically impair the quality of the system. This can happen due to the nonexistence of components which are required for a system to function, due to capacity constraints on the flows in a system, or due to mismatched components. These technical bottlenecks, become strategic bottlenecks when firms can control the technical bottlenecks, when there are no substitutes, and when it is difficult to imitate them.

Jacobides et al. (2006) provide a similar argument regarding the strategic value of complements in a market architecture, based on complementarity and mobility. Firstly, since complementarity determines the value that can be created, this creates dependencies among complements. In turn, when the complements are held by different actors, this then creates dependencies between actors. Secondly, mobility refers to the amount of possible combinations. In this sense, it is a measurement of how easy it is to switch between alternative complements. In other words, the more alternative complements one can choose from, and the easier it is to switch between them, the higher mobility becomes. Higher mobility thus implies competition in these complements, which makes the parts where there is low mobility and competition more valuable. As such, the bottleneck complements of a market architecture, are those complements where mobility is low, relative to the other complements of the architecture, without decreasing complementarity among them.

Impacting market architectures

Having discussed on a higher level why market architectures emerge, and the structure that is expected to ensue in the case of modularity and nongeneric complements, one might be quick to assume market architectures to be exogenous, and that there is little to be done to influence them. According to many academics however, organizations are found to be capable of having deliberate impacts on how markets are shaped (e.g., Jacobides et al., 2018; Jacobides et al., 2006; Pisano and Teece, 2007; Ozcan and Santos, 2015). Market architectures do not only define who provides which components of a product offering, but also how firms interact, and how risks, costs and profit are shared. These factors are all shaped through cognitive and structural processes, which in turn are processes shaped by individual actors (Ozcan and Santos, 2015). For instance, Ozcan and Santos (2015) find that when industries come together in the development of a new market, disagreements between dominant firms may emerge, over how the market will be structured. That is, these parties typically try to secure positions of dominance in new markets, and continuing disagreements about who secures dominance may even lead to markets not emerging altogether. What can be concluded from this, is that in the formation of market architectures, the agency of individual firms, and the negotiation processes among involved actors, can influence the architecture of a market, and can be key in markets coming into existence in the first place. Because of this, Ozcan and Santos (2015) posit, that market architectures need to be actively shaped. Firms continuously try to improve their positions, which might constitute redesigning the technical- and market architectures, thereby rendering other organizations redundant (Dattée et al., 2018), or which might constitute moving into other parts of an ecosystem to compete with actors, that firms were previously collaborating with (Hannah and Eisenhardt, 2018; Dattée et al., 2018).

Multi-sided markets

Typical structures which emerge in the layered modular architectures are multi-sided markets (Yoo et al., 2010). Multi-sided markets are markets "in which one or several platforms enable interactions between end-users, and try to get the two (or multiple) sides on board by appropriately charging each side" (Rochet and Tirole, 2004, p. 1). At the foundation of multi-sided markets lies the notion that end-users do not internalize the cross-market externalities of their activities. That is, the more that use mobile applications, the more valuable it becomes for a developer to develop applications. However, people that use mobile applications do not take into account this effect on the other side of the market. This creates a situation in which a surplus of value is created which the end-users cannot negotiate over. Moreover, end-users that are engaged in a multi-sided market cannot efficiently negotiate over value when there are transaction costs among them, when the platforms impose constraints on pricing, and when there are fixed fees for participating in the market. The result is that changes in the price structure cannot be passed on to other end-users, thereby influencing the total demand, which is exactly what distinguishes multi-sided markets (Rochet and Tirole, 2004).

3.3 Uncertainty

The context which has been outlined so far, is one in which the introduction of new technologies in layered modular architectures enables the creation of a large variety of new value propositions, and in which, for these value propositions, market architectures have to be actively shaped. The introduction already described that the processes relating to these concepts are of an uncertain nature, and the previous sections also occasionally mentioned such. This section will focus on describing that uncertainty.

Uncertainty in the described context follows from a number of factors. First of all, due to the generativity of the technology, it becomes impossible to predict exactly which value propositions will be developed in the future (Dattée et al., 2018). This effect is exacerbated in layered modular architectures, as in such architectures combinatorial innovation becomes possible, which makes it impossible to predict for which purposes complementors will use the architecture (Yoo et al., 2010). Therefore, it will also become difficult to determine which value propositions to commit resources to, and to create compelling visions to attract complementary actors. Furthermore, as it becomes difficult to envision the exact nature of future value propositions, it becomes even more difficult to determine which strategic positions in these value propositions will make it possible to appropriate value from them (Dattée et al., 2018).

Cennamo (2018) shows that a similar logic can be found in the initial phase of competing next-generation platforms acting in multi-sided markets. In such markets there is uncertainty among users and complementors around what the platforms' value is, and which platforms best suit their needs. That is, there is technological uncertainty around the platform itself, around which complementarities can be developed, and around how these complementarities can be developed. Derived from this, there is also uncertainty about how large the installed base will be. For this reason, both users and complementors will consider alternatives in the initial phase, which is why a key part of platform development is to attract complementors.

Jacobides et al. (2018) argue that in modular architectures, the type of complementarities impacts the fungibility of committed resources. Complements that are generic in nature, are those complements that are highly standardized, easy to acquire, and can be used for many different purposes. As such, investments in generic complements pose little risk, as these investments can be easily redeployed. Contrasting generic complements, nongeneric complementarities require investments that cannot be completely redeployed. As such, there is a risk in designing highly specific complementarities on the basis of a modular architecture, as in the case of commercial failure, these investments might become indefinitely lost. This also creates uncertainty for the developer of the modular architecture, as this might complicate attracting the right complementors.

Hannah and Eisenhardt (2018) find that the types of uncertainty encountered also depend on the strategy that a firm is pursuing in a market consisting of multiple complementary components. That is, if a firm pursues a system strategy, thereby aiming to take control over all the system components, there is uncertainty and risk in that it will initially take time and money to develop and integrate all these components efficiently. Therefore, scaling will become difficult, which might result in lagging behind competitors. When survival in a market depends on having a sufficiently large installed base, this then poses uncertainty around the survival chances of a firm pursuing the system strategy. Moreover, if future demand changes, firms pursuing this strategy might be at risk of having capacity problems in individual components. There are also firms aiming to focus only on one component of the system. For these firms, it becomes essential to cooperate with others that provide complementary components. This creates uncertainty, as selecting the best complementors might not be a straightforward job. Furthermore, it was mentioned above that complementors are not necessarily willing to commit to a value proposition. Finally, there is uncertainty around which components will be strategically most important for the value proposition, which is something that may change over time as well (Hannah and Eisenhardt, 2018).

As was mentioned before, there is quite a lot of uncertainty surrounding the formation of market architectures (Ozcan and Santos, 2015). First of all, there is cognitive uncertainty around what the product exactly is. For example, Rosa and Spanjol (2005) show how actors' shared knowledge about a product evolves, through their analysis of the stories which market actors use to describe the product. That is, actors initially describe products vaguely and ambiguously, in a complex manner, and do not know on which dimensions to compare products effectively. Secondly, there is structural uncertainty, which is tied to the processes underlying the formation of the structures around which markets are formed. That is, based on the literature on dominant designs (Anderson and Tushman, 1990; Suárez and Utterback, 1995), there are many factors which influence whether a new radical technology becomes the standard. Firstly, following the dynamic capabilities view, the path dependent nature of innovation processes implies a degree of irreversibility, meaning that organizations typically are unable to switch to other innovation paths once sufficient resources have been dedicated to a specific path (Teece, Pisano, and Shuen., 1997). In other words, when organizations focus on one technology or technical architecture, they often cannot easily redeploy resources to other technologies. Secondly, whether a technical architecture becomes the dominant design, also depends on the amount of users. A technology may be superior in technical terms, but if it does not attract any users, it will never become the dominant standard. This creates network effects, as an increase in the amount of users leads to an increase in the value of the technology path of interest (Katz and Shapiro, 1994). The consequence of these underlying processes, is that in the creation of technical- and market architectures, there typically is uncertainty around committing to the right technologies, and around attracting sufficient users for a technology to become economically viable. Apart from these, Ozcan and Santos (2015) describe how firms will also experience uncertainty in forming a market. Dependent on the power a firm has in shaping a market, and its history of dominance, a firm may wish to exert strong influence over the market architecture. As this potentially is the case for multiple firms, this creates uncertainty around the division of roles in the market.

3.4 Dynamism

Because of the uncertain nature of the context, and because of the large variety of potential value propositions, the processes underlying the formation of technical- and market architectures are also of a dynamic kind.

It was established that due to the introduction of a new generation of technology in layered modular architectures, a situation emerges in which many new value propositions are becoming possible. In such a situation, in which the possibilities are large and the uncertainty high, the processes driving the creation of new value propositions are dynamic ones. Dattée et al. (2018) identified how these processes are driven by a number of feedback loops. First of all, the further a technology is in its development, the clearer it becomes for which purposes it can be used, which lowers the range of possible futures. This in turn leads to a process in which actors roles are defined, leading to clarity on technological and social interdependencies. The result of increasing clarity on these aspects, is that both external and internal momentum will increase accordingly. That is, both a focal actor and external complementors will start committing resources increasingly as uncertainty decreases. Such increased commitments in turn lead to further development of the state of the technology, closing the feedback loop.

Another dynamic feedback loop which Dattée et al. (2018) encounter, follows from the notion that an increase in clarity of social and technological interdependencies, will make it clearer for individual firms which points or components in the system are of most strategic value, in turn leading to internal momentum to capture these points. Another important phenomenon to take into account, is that the commitment a focal firm has in a certain project, can positively influence the commitment of external partners. Similarly, commitments of external partners positively influences the commitments of a focal company. Therefore, this creates a reinforcing feedback loop. Organizations are typically hesitant in committing resources, which is why, from a focal actor perspective, it is important to build up internal momentum to secure both internal and external commitments.

Finally, Dattée et al. (2018) conclude that developments around a technology can also lead to an increase in the range of alternative futures, as new combinations or applications are discovered. As such new applications are discovered, a phenomenon called drifting might occur, in which actors start focusing on other applications. When this happens, the interdependencies become less clear again, which will also make it less clear which positions in the system are of most strategic relevance. This is why in the development of a technology and its applications, shifts can occur in which actors hold the most strategic positions.

In platform markets, Cennamo (2018) finds evidence that the amount and quality of complementarity activity dynamically influence the value of a platform. In the initial phases of a platform, stimulating complementary activity can increase the rate of innovation. Knowledge can be generated on how to create complements, and how to connect them efficiently to the platform. Therefore, stimulating complementary activity can increase the variety and quality of complements. However, as technological development progresses, having a large installed base of complementors might have negative consequences. That is, if a market of complementors is stimulated too quickly, the incentives for newcomers might be too low to join the platform. An early saturated market of complementors might thereby constrain the variety and quality of complements in later phases of the platform's life. A similar pattern is found for complements that are developed in-house. In the initial phase of a platform, creating complements in-house can showcase the technology's potential to external complementors, can generate knowledge on how to create qualitative complements which might be transferred to external complementors, and it shows the commitment of the platform owner, which all can lead to increased complement variety and quality. At later stages however, creating complements in-house might get in the way of the external complementor's ability to appropriate value. Therefore, later on in the platform's life, high levels of in-house complement activity will lead to lower complement variety and quality.

Two other factors which influence the dynamics in coordinating activities, are fungibility and the type of complement (Jacobides et al., 2018). As was mentioned before, due the coordination necessary for supermodular and unique complements, investments are required that cannot easily be redeployed. On the one hand, if investments cannot be redeployed, then actors will be more dedicated to seeing their complements and the system succeed. On the other hand, low fungibility will make actors less eager to design specific complements. Jacobides et al. (2018) further argue that these dynamics are also to be expected to differ in nascent versus mature contexts. This makes sense, as it was earlier argued that in nascent settings, uncertainty is especially high. Then, in such uncertain contexts of the initial phase of generative technologies, it is to be expected that it will be especially hard to convince actors to develop unique or supermodular complements, if the fungibility of their investments to develop these complements is low. Similarly, actors might refrain from stimulating others to develop nongeneric complements, if it would require low fungible investments on their part to coordinate the integration of these complements.

Another dynamic found in the described contexts, is that the components which strategically have the most value, can change over time (Hannah and Eisenhardt, 2018). As technology develops over time, costs in one bottleneck can fall, or new solutions can be discovered, which can then create another bottleneck. The dynamics relating to these bottlenecks also depend on the strategies of individual actors, and on the maturity of a system (Hannah and Eisenhardt, 2018). Those that follow a bottleneck strategy, aim to always be in the component which is the bottleneck of the system. They will compete in the bottleneck, and collaborate with complementors. They will focus on keeping track of which components are the bottlenecks of the system, and then on entering those bottlenecks. This requires specific capabilities in keeping track of shifts in the system, and in developing new capabilities. Furthermore, firms with a bottleneck strategy will have to deal with changing roles of complementors. Firms that used to be complementors may become competitors, and vice versa. Firms that follow a component strategy, focus on one specific component, or a few. These firms aim to cooperate with the other roles that can be found in a system, and create value through co-specialization and innovation in their component. When their component becomes a complement, or the other way around, this can have profound impacts on their behavior. Those following a system strategy will aim to secure all, or most, components of the system. These firms typically focus on integration, and compete with other systems.

Additionally, it is not only the strategy which determines the dynamics relating to bottlenecks. That is, the characteristics of the bottlenecks also play an important role. It was already stated above that there are different types of technical bottlenecks, with different implications for organizations (Baldwin, 2015). Also, whether a bottleneck is a unique or supermodular complement has influences on the coordination structures (Jacobides et al., 2018). The location of a bottleneck also matters. That is, when a bottleneck lies deep in the layers of a layered modular architecture, it has more potential for enabling the creation of many innovations (Yoo et al., 2010; Dattée et al., 2018). Therefore, there is more uncertainty surrounding bottlenecks that lie deeper in an architecture, than around bottlenecks that find themselves more on the surface. Furthermore, Adner and Kapoor (2010) find that the location, based on the flows of inputs and outputs, also determines the impact of bottlenecks on innovation and the potential for value capture. Finally, Hannah and Eisenhardt (2018) find that how crowded a bottleneck is, also influences dynamics. If there are many firms active in a bottleneck, then the focus will often be on innovation in that bottleneck. However, if a bottleneck is uncrowded, firms in the bottleneck will focus on exploiting their position by capturing value.

3.5 Capturing and creating value

Having described the context from an academic perspective, the question then turns to how to strategically act in that environment. That is, the context outlined above, as one of layered modular architectures, with typical sources of uncertainties and dynamics, has implications for how firms should both create and appropriate value.

A first critical consideration, is how to manipulate technical- and market architectures in such a way, that an advantageous situation is created for a focal firm (FF). In markets that are characterized by nongeneric complements, a general rule appears to be to manipulate the architecture in such a way that one becomes the bottleneck (e.g., Jacobides et al. 2006; Pisano and Teece, 2007). There are multiple ways through which this can be achieved. Jacobides et al. (2006) state that firms should focus on changing the architecture it is embedded in, by stimulating mobility in complementary components, and by restricting mobility in its own components. Simulating activity in complementary assets can be done, through increasing modularity. That is, modularity, being the thin crossing points between components, is allows what allows others to easily connect to the components of the FF. In this sense, modularity includes the design of both technical mechanisms such as Application Programming Interfaces (APIs) and Software Development Kits (SDKs), clearly defined standards, but also social mechanisms such as incentives (Jacobides et al., 2018; Yoo et al., 2010). Through the employment of such mechanisms, thereby making it easier for other actors to develop complements, competition in these complements will increase. As such, there will be more alternative complements, and it will be easier to switch among them, which increases the strategic value of the position of the FF. This logic can be summarized in the following design principle:

1. In markets characterized by nongeneric complements (C), the FF should increase modularity, by means of technical mechanisms such as APIs and SDKs, use of standards, and use of social mechanisms such as incentives (I), since, through making it easier to develop complements, mobility in complementary assets will increase, thereby increasing competition in these complementary assets (M), which in turn will decrease the value of these complementary assets, relative to the assets where the FF is active, which in turn creates an architectural advantageous position for the FF (O).

Following the above logic, it also holds that while stimulating complementary activity, a FF should focus on limiting the amount of mobility, and therefore competition, in its own segment (Jacobides et al., 2006). Specifically, Pisano and Teece (2007) propose a logic as to how this can be achieved. According to them, in order to be able to appropriate value, companies should be concerned with protecting those components that are critical in terms of strategic value. One of the critical ways through which this can be done, is through strengthening the appropriability regimes. An appropriability regime is that which protects a company from imitation. One can think of legal mechanisms such as patents, copyright protection and contracts, but also factors such as how difficult it is to reverse engineer an asset. Pisano and Teece (2007) provide the source code as an example, which is a part of software that can be shielded. Another obvious and well established means of protecting intellectual property, is the use of patenting. This results in the following design principle:

2. In parts of a market architecture where the FF is active (C), the FF should restrict mobility by strengthening the appropriability regimes (I), since, through an increase in barriers of entry and a decrease in competition (M), the value of these assets increases, relative to complementary assets in which the FF is not active, which creates an architectural advantageous position for the FF (O).

Apart from strengthening appropriability regimes, Pisano and Teece (2007) argue that one may also opt for weakening these regimes. They mention open source software as one example, in which software is made publicly available. Through doing this, one can prevent that a valuable component of a system is owned by a limited amount of actors. So, when one makes software open source, then companies that try to gain an asset position in the software part of a system will be hurt, whereas companies that hold assets in, for instance, the hardware part of that system, will benefit. Pisano and Teece (2007) also give examples of how actors developed specific (potential) strategic components, to then make them publicly available, such that their own core components remained revenue generators. This logic then results in the following design principle:

3. For those components in which the FF is not active, and which hold strategic value (C), the FF should focus on weakening the appropriability regime for these components by developing them and making (parts of) them publicly available (I), since the public availability of such components will weaken their strategic value (M), which will increase the relative strategic value of the components that the FF does hold (O).

In the dynamics section, it was also described how Jacobides et al. (2018) explain that the type of complementarity, and the fungibility of the tied investments, matter in terms of the interactions between involved actors. Specifically, it was stated how it might be difficult to attract developers of highly specific complements with low fungibility, especially in the initial phase when uncertainty is high. At the same time, for those actors that are already committed to a certain offering, it might be beneficial to stimulate low fungible investments, as this would increase their commitment to seeing things succeed. The implication is that when involved in a layered modular architecture, the FF should consider the type of the complements that other actors make, and the fungibility of the investments that these actors need to make, in order to develop those complements. Specifically:

4. In attracting developers of complements for a layered modular architecture, especially in the initial phase of a market (C), the FF should aim for complements that require investments that are relatively high in fungibility (I), as, through a reduction of the fear of being locked in (M), this would make complementors more eager to participate (O).

5. For those complement developers that are already tied into the layered modular architecture (C), the FF should aim to let these complements be supermodular or unique, and low in fungibility (I), as this will make participants more eager to make the combined product succeed (M), thereby increasing the potential value of the layered modular architecture and its complements (O).

According to Cennamo (2018), not only variety in complements is needed, but also quality. Cennamo (2018) finds that the amount of third-party complementary activity and the number of components that are produced in-house, influences the value that is eventually created by the platform. Furthermore, these influences differ over time. The dynamics themselves have already been described in the dynamics section, but there are obviously important implications for how value creation and appropriation should be managed. That is, in the early stages of a new generation of technologies, platforms should focus on attracting third-party complementors and on developing a number of in-house complements. Through doing so, uncertainties about the platform capacities and the likelihood of success are decreased, knowledge spillovers can be created, and incentives to innovate are created, all leading to higher quality and variety of complements, which in turn generates more value for the platform. This is captured in the following design principle:

6. In the initial phase of a platform market (C), the FF should aim to attract third-party complementors and build in-house complements (I), as this reduces uncertainties related to the platform, opens up the opportunities for knowledge spillovers, and creates incentives to innovate through competition (M), which would then lead to a higher quality and variety of components, and a higher value of the platform (O).

As was explained before, how the FF creates and appropriates value, also depends on whether the FF follows a system strategy, a component strategy, or a bottleneck strategy (Hannah and Eisenhardt, 2018). Based on the stance of the telecom business that was described in the introduction, and based on the generative nature of the technical architecture of 5G, it seems unlikely that companies in the telecom world will adopt a system strategy, which is to account for all components in all possible product offerings. For this reason, how to create and appropriate value will be defined along the lines of reasoning of a component or a bottleneck strategy. When following a component strategy, which does not have to be a bottleneck, the implication is that the FF has to rely on complementors for the rest of the product offering. This implies a degree of risk, as what can happen is that firms do not gain access to the complementary components, thereby becoming unable to deliver a value proposition. This is also why a component strategy relies heavily on cooperation capabilities. Cooperation should also be increased over time, to eventually develop specialized ties with complementors. This creates a situation of co-specialization, which would reduce transaction costs and increase switching costs. Furthermore, innovation is key when following a component strategy, both in collaboration, and in the component the firm offers, as this is a way to stand out. This logic results in the following design principle:

7. When following a component strategy (C), the FF should focus on collaboration, and on innovation in both its collaborative aspects and its components (I), as this will let the FF be able to have access to complementary components, and to differentiate itself from other component competitors (M), which will enable the FF to survive over time (O).

When following a bottleneck strategy, the aim is to always be in that component of the market architecture, which is the bottleneck. This means that once the bottleneck components changes over time, firms following this strategy should enter the component of the market architecture which has become the bottleneck. A bottleneck strategy relies on both competition and cooperation, which mainly depends on how crowded the bottleneck is. As the context of an operator in the Dutch market is inherently one of competition, the implication is that in general, the operator will find itself in a crowded bottleneck position, if a bottleneck position is indeed achieved. Then, when many firms are active in the bottleneck component, the FF should focus on innovation in the bottleneck to be able to stand out, and on cooperation with other complement providers. In the cases of Hannah and Eisenhardt (2018), this implied helping their complementors with improving their capabilities, which in turn can help in improving the overall product offering. By adopting this logic, design principle 7 can be updated to the following:

7. When following a component strategy, or a bottleneck strategy in a crowded bottleneck (C), the FF should focus on collaboration, and on innovation in both its collaborative aspects and its components (I), as this will let the FF be able to have access to complementary components, and to differentiate itself from other component competitors (M), which will enable the FF to survive over time (O).

One work which has focused on the dynamics which can take place in settings of generative new technologies, is that of Dattée et al. (2018). In the previous section these dynamics have been described, and the important implication was that there are quite a few dynamics taking place that can influence the strategic position of the FF. That is, bottlenecks, or control points, may change over time, new applications may be discovered resulting in uncertainties about where to focus resources on, firms that are currently cooperating, might wish to compete for bottlenecks in the future, and so on. In order to deal with these dynamics, Dattée et al. (2018) found that certain strategies are used, called dynamic control. This dynamic control has three elements, which are influencing, monitoring, and updating.

I. First, influencing is about shaping the future in that way which is beneficial to the FF. The FF should therefore continuously aim to narrow down the future, to make increasingly clear how the roles for making a value proposition are defined, and to increase both internal and external commitments to the envisioned future. This means that a FF should focus on influencing the collaborating actors onto the paths that the FF envisions. Mentioned mechanisms that can be used to do this are conferences, meetings, and so on. Furthermore, in the technical- and market architecture that the FF envisions for a certain value proposition, the FF should focus on capturing the bottleneck components in those architectures.
II. Second, the FF should continuously monitor its environment. That is, the FF should specifically monitor the broader environment on whether new applications are being discovered, on whether partner firms are potentially assigning commitments to other applications, on whether bottlenecks are changing, and so on. Mechanisms through which this can be done are through conferences, through cooperating on shared roadmaps, or sending each other continuously updated individual roadmaps, and so on.
III. Third, the FF should update its strategies based on the information that comes out of its monitoring processes. This might entail updating blueprints for the architectures of the value propositions, it might entail focusing on different value propositions, focusing on different bottleneck components, using different mechanisms to influence others, et cetera.

This logic of dynamic control, can be captured in the following design principle:

8. In the initial phase of a generative technology in a layered modular architecture (C), the FF should exert dynamic control (I), since through influencing and monitoring their environment, and through updating their strategies (M), the FF will be more able to commit resources to the right applications, to gain control over bottlenecks, and to make sure partners also keep committing to the right applications, meaning that the FF will be more able to create and appropriate value (O).

Finally, there is an important consideration to be made in the context where dominant organizations from diverse industries come together, in the emergence of new markets. Ozcan and Santos (2015) show that in such a setting there are conditions which could prevent a market from emerging altogether. For this reason, when there are multiple dominant firms from different industries involved in the emergence of a new market, they advise that firms should not aim to dominate the new market. Instead, firms should aim to develop architectures which could be beneficial for all these dominant firms, which would then allow a market to emerge.

9. In the phase where actors focus on letting a new market emerge, and where dominant players from different industries are involved (C), the FF should not attempt to dominate the market architecture but instead focus on developing a market which is beneficial to all dominant players (I), as this would prevent the vicious cycle of resource allocation deferment from occurring (M), thereby giving a market a chance to emerge (O).

3.6 Design principles from theory

Based on the previous sections, a list of design principles has been created which would allow the FF to create and appropriate value in the described context. This list is again presented here:

1. In markets characterized by nongeneric complements (C), the FF should increase modularity, by means of technical mechanisms such as APIs and SDKs, use of standards, and use of social mechanisms such as incentives (I), since, through making it easier to develop complements, mobility in complementary assets will increase, thereby increasing competition in these complementary assets (M), which in turn will decrease the value of these complementary assets, relative to the assets where the FF is active, which in turn creates an architectural advantageous position for the FF (O).
2. In parts of a market architecture where the FF is active (C), the FF should restrict mobility by strengthening the appropriability regimes (I), since, through an increase in barriers of entry and a decrease in competition (M), the value of these assets increases, relative to complementary assets in which the FF is not active, which creates an architectural advantageous position for the FF (O).
3. For those components in which the FF is not active, and which hold strategic value (C), the FF should focus on weakening the appropriability regime for these components by developing them and making (parts of) them publicly available (I), since the public availability of such components will weaken their strategic value (M), which will increase the relative strategic value of the components that the FF does hold (O).
4. In attracting developers of complements for a layered modular architecture, especially in the initial phase of a market (C), the FF should aim for complements that require investments that are relatively high in fungibility (I), as, through a reduction of the fear of being locked in (M), this would make complementors more eager to participate (O).

5. For those complement developers that are already tied into the layered modular architecture (C), the FF should aim to let these complements be supermodular or unique, and low in fungibility (I), as this will make participants more eager to make the combined product succeed (M), thereby increasing the potential value of the layered modular architecture and its complements (O).
6. In the initial phase of a platform market (C), the FF should aim to attract third-party complementors and build in-house complements (I), as this reduces uncertainties related to the platform, opens up the opportunities for knowledge spillovers, and creates incentives to innovate through competition (M), which would then lead to a higher quality and variety of components, and a higher value of the platform (O).
7. When following a component strategy, or a bottleneck strategy in a crowded bottleneck (C), the FF should focus on collaboration, and on innovation in both its collaborative aspects and its components (I), as this will let the FF be able to have access to complementary components, and to differentiate itself from other component competitors (M), which will allow the FF to create and appropriate more value (O).
8. In the initial phase of a generative technology in a layered modular architecture (C), the FF should exert dynamic control, by influencing and monitoring their environment, and by updating its strategies (I), since through an increased ability to commit resources to the right applications, to gain control over bottlenecks, and to make sure partners also keep committing to the right applications (M), the FF will be more able to create and appropriate value (O).
9. In the phase where actors focus on letting a new market emerge, and where dominant players from different industries are involved (C), the FF should not attempt to dominate the market architecture but instead focus on developing a market which is beneficial to all dominant players (I), as this would prevent the vicious cycle of resource allocation deferment from occurring (M), thereby giving a market a chance to emerge (O).

4. Results

This chapter will describe the findings of this study. In accordance with the literature of the previous chapter, the next sections will first focus on describing both the market- and technical architectures relating to the setting of 5G-related business innovation. This will be followed by the conceptual themes which best describe this environment. Based on these themes and findings of the research, design principles from practice will be presented.

4.1 Technical architecture

This section will now describe the technical architecture of innovations based on 5G. First, some of the key technical characteristics of 5G will be described, as mentioned by interviewees. After having described the general elements of 5G network technology, this section moves on to describe the modular nature of the technology, and the technical interfaces between the network of an operator, and the applications that are to be developed.

4.1.1 General characteristics

Based on the interviews, key characteristics of 5G technology were derived, which are presented in Table 2. First, it should be pointed out that the general key characteristics, that were mentioned by the interviewees, were mostly in accordance with what the earlier empirical research on 5G suggested. From Table 2, it can be seen that interviewees see antennas with beamforming technology, edge computing or decentralization, the increase in spectrum and the use of higher frequencies, and the concept of network slicing, as the most important components of 5G. Similarly, as specified in the introduction, these new technologies lead to certain functional improvements, which are an increase in speed, reliability, capacity, the amount of devices that can be connected, and a decrease in the latency.

Construct	Description
Most important components	
Antennas with beamforming technology	Provides the capability to target individual users.
Edge computing	Processing power will be placed at the edges of the network, instead of in the core data centers of an operator. This means the processing of data will happen closer to the user.
More spectrum and higher frequencies	More frequency bands, and higher frequencies, will be used for data transmission.
Network slicing	Network slicing creates virtual networks, which can cater to the requirements of individual users.
Functional characteristics	
Capacity	Due to the use of more spectrum bands and higher frequencies, more data can be processed.
High reliability	Due to concepts such as network slicing and beamforming, guarantees on network performance can be given.
Low latency	Due to data being processed closer to the user, the time between sending and arrival of data will be significantly shortened.
Many devices, low power	Due to concepts such as network slicing, it becomes possible to connect many devices with low energy consumption.
Speed	Due to the use of higher frequencies, data can be transmitted at higher speeds.
Difficulties or constraints	
Providing coverage everywhere	In settings with metal, steam, buildings, et cetera, which can cause interference, it can be difficult to provide coverage.
Possibilities are not limitless	You cannot offer all functionalities simultaneously.
Applications	
Generativity	There are many possible applications based on the underlying layered modular architecture.
The application determines the combination of functionalities needed	Applications that are being envisioned require a certain combination of functionalities and components.
Complementarity	The applications that are envisioned in general require complementary components.
Alternatives	
Alternative architectures	There are some alternatives to the technical architecture of 5G networks which currently seem important to the Dutch market.
Connectivity alternatives	Apart from 5G, there currently are also other connectivity technologies that in certain settings may be good alternatives.

Table 2: Key characteristics of 5G based on interviews

Before going into a little bit more detail regarding the above concepts, what first should be described is what the general architecture of a 5G network are. As described in the methodology, for this purpose mostly whitepapers, from standardization bodies and companies from the telecom industry, were used. The interviews provided the insights, as to for which concepts to search.

Figure 5 presents a representation of the overall architecture of a 5G network, as envisioned by the 5G Infrastructure Public Private Partnership (5G PPP), which is a standardization initiative from the European telecom industry and the European Union. From this figure, it can clearly be concluded that the architecture indeed follows a layered and modular idea. That is, at the lower levels of this conceptualization, the architecture consists of the physical components that make up a telecommunications network. Elements such as the antennas connect devices with a mobile connection to the mobile network of an operator. Then, moving up the hierarchy, the service logic of the network can clearly be seen. Central in this representation is the concept of network slicing, which provides a logical service layer tuned to specific service requirements (5G.co.uk, 2018). Then, based on that logic, actual services can be created on top of the network.

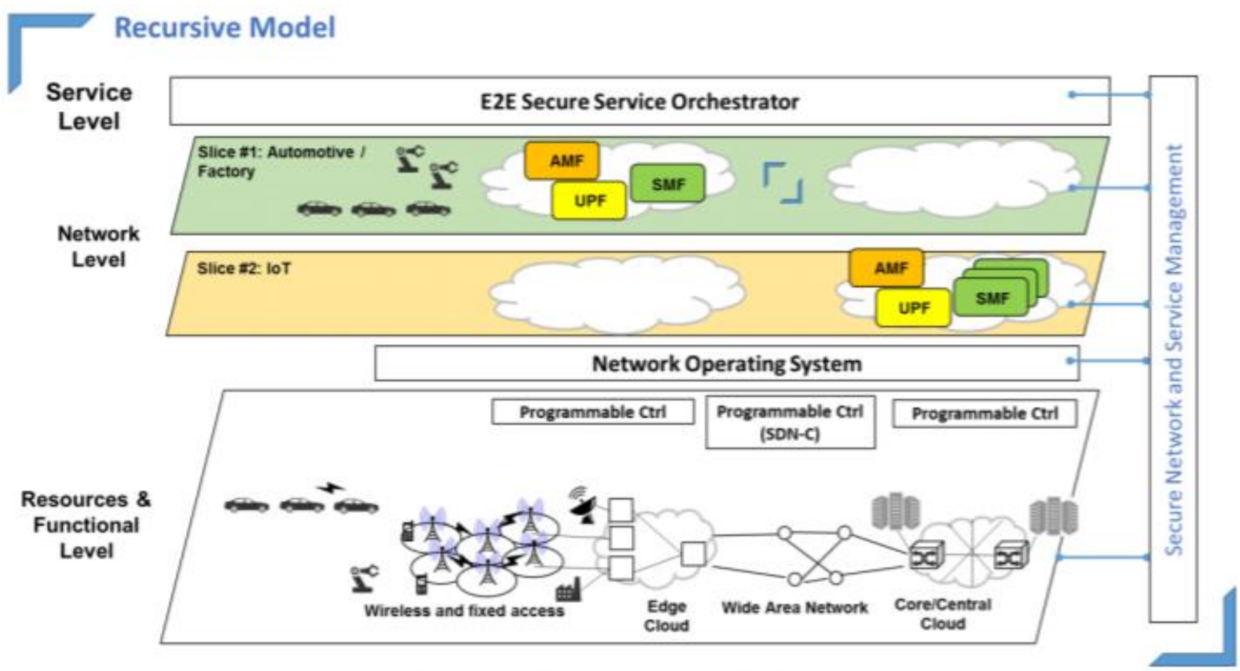

Figure 2-1: Overall Architecture

Figure 5: Architecture of a 5G network (5G PPP, 2019)

Most important components

In the new network architecture that 5G brings, there are some components which are critical for the types of services that can be created. A first, already often mentioned one, is the concept of network slicing. Many of the interviewees consider network slicing as one of the most crucial components of the new 5G network architecture, as this is the component of the network which allows for making promises to customers. Network slicing allows an operator to create logical networks on top of a shared physical infrastructure (5G PPP, 2019; Huawei, 2016; Nokia, 2016; Ericsson, 2018b). This can be achieved through concepts that are called software-defined networking (SDN) and network functions virtualization (NFV). Due to these concepts, it becomes possible to separate software from hardware, and to dynamically manage a slice based on real-time needs (Nokia, 2016). The implication is that it becomes possible to create an end-to-end slice, which can have tailormade functional characteristics on latency, speed, reliability, and capacity. These NFV and SDN concepts, in fact greatly change the nature of the architecture of a telecommunications network. That is, rather than having one big standardized block which performs all functions similarly, the architecture is changing to a modular design, in which customers choose the blocks of the network that best suit their needs.

Another important concept mentioned by interviewees is that of Multi-access Edge Computing (MEC). With MEC, capabilities for computing, analysis and storage are placed at the edges of the network (Ericsson, n.d.; Qualcomm, 2019). The consequence of this is that the radio path travelled by data can be greatly reduced, thereby shortening the latency (Hu, patel, Sabella, Sprecher, Young, 2015; Cisco, n.d.). Furthermore, because data does not have to travel all the way to the core centers of an operator, this is also a concept which will help in relieving the pressure on the network.

Furthermore, some interviewees mentioned how the employment of extra bandwidth and new frequencies in the millimeter wave domain, will help in addressing the increasing demand of data. This demand is already continuously increasing, and especially new types of applications will require even more data. Thus, more available bandwidth will allow for more network capacity to address that demand (Deloitte, 2018a; Andrews et al., 2014; BCG, 2018). Also, the increase in frequencies will mean that the data speed will increase as well (Boccardi, Heath, Lozano, Marzetta, Popovski, 2013; Deloitte, 2018a).

Finally, one interviewee mentions how there are also important developments in the antennas that are going to be used. Due to massive MIMO technology, the spectral efficiency increases, in bits/s/Hz per node, by employing more antennas than users at base stations (Andrews et al., 2014; Boccardi et al., 2013). What used to happen, was that the radio waves were spread in a spherical manner, thereby sending a significant part of the data, to where it was not needed. Based on the concept of beamforming, the use of more antennas allows for the formation of beams in the direction of connected devices, resulting in stronger signals for users, and less data loss, or interference leakage. This is graphically depicted in Figure 6. Furthermore, massive MIMO increases the link reliability, and allows for range extensions, or for higher data rates on already covered places, or for covering the same range with reduced power (Björnson, Hoydis, Sanguinetti, 2017).

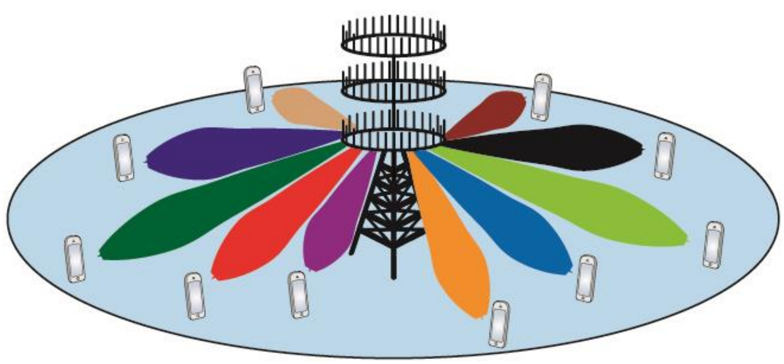

Figure 6: Massive MIMO (Björnson, 2016)

Functional characteristics

The abovementioned technologies, and others, result in some important functionalities that can be delivered. Many interviewees mention how increases in capacity, in speed, in the amount of devices that can be connected with a low energy consumption, and in reliability, are very important characteristics for many applications that will be developed. Moreover, a crucial factor is that with 5G, reliability will be such, that operators will become able to make guarantees on their network performance, allowing them to make Service Level Agreements (SLAs). This is something, that operators currently do not offer.

Applications

Based on these components and functional characteristics, many applications can potentially be developed. Many interviewees mention a host of applications which are currently being piloted. Furthermore, one should note that it is the type of application, which determines what functional characteristics are needed. That is, there are applications which require complete reliability, sometimes combined with a very low latency. Examples of this could be communication with safety services. Next, there are applications which require speed and capacity, for instance in video streaming. Combined with low latency, one could also think about new services in augmented reality (AR) and virtual reality (VR). Finally, there are those applications which require many devices to send data, with a low power consumption. One respondent gave an example about placing sensors on a dyke, to monitor it for preventive maintenance purposes. The data that these sensors transmit are usually very small packages. In other words, you do not need a lot of network capacity for these individual sensors. However, what you do need is that these sensors last a long time, and that you can connect with many of them. The conclusion is that for these kinds of applications you specifically need low power consumption sensors, and a network that can connect with possibly a great many of them.

Another important characteristic of the applications that are currently being developed in pilots across the country, is that they all consist of complementary components. As one respondent states, this is probably something that relates to the digitalization of environments. That is, in many of our existing environments, digital elements are added to improve or automate existing processes. This almost necessarily creates a world in which no party can do it alone. That is, there are not that many parties which have the knowledge, and the assets, to create the specialized kinds of applications that are currently being developed. For instance, for an automated harbor or factory, you would need superior connectivity, sensors, robotics, artificial intelligence, specific knowledge of the processes in those environments, and so on. The implication is that right now multiple parties are coming together to collaborate on such concepts, and that these parties all provide components that complement each other, in order to arrive at final applications.

Difficulties or constraints

Apart from the above points, there are currently also some general difficulties or constraints that were identified by the interviewees. First of all, it should be noted that it is no coincidence that the abovementioned applications require a combination of the possible network functionalities. That is, due to basic science, the possible functionalities cannot be delivered all simultaneously. So, the network is limited in the sense that an operator cannot provide high speed, capacity, low latency, high reliability, and all of that to a great number of devices, all at the same time. It does not seem to be an extreme limitation, as multiple interviewees mention that this does not restrict the applications that are going to be created. Yet it was mentioned by interviewees as important to understand, as it has implications for how an operator differentiates the functionalities of its mobile network.

Furthermore, another issue which interviewees mention is that providing coverage everywhere might be a challenge. For instance, closed spaces, or locations that contain metal or steam, may cause interference, which makes it difficult to provide coverage. Similarly, buildings may obstruct a signal, and also in places where there are many people using their phones, coverage can be challenging.

Alternatives

There are also some alternatives to the technical architecture of 5G, that seem to be relevant for market considerations, according to the interviewees. First of all there are alternatives to the architecture itself. One interviewee explains how operators can choose between two alternatives, if they want to upgrade their network toward 5G, which are standalone and non-standalone 5G. Non-standalone means that an operator upgrades its 4G core, so that it can also function with 5G. However, an operator will still have a 4G network, with 4G functionalities. What that means is that an operator will have extra capacity, and 5G speeds on the 5G spectrum bands, but not the other core functionalities that allow for the specialized services which have been mentioned above. Operators that go this way, might do so if they want to be first in offering 5G, if they want to offer 5G speeds, or if they need the extra capacity on their network to prevent congestion (Ericsson, 2019). These operators will then have to move to a standalone 5G core network afterwards. The other option is to upgrade immediately to a standalone 5G network. However, according to the interviewee, this is not yet something that is seen in the market. Operators that are aiming for this, are, according to the interviewee, likely to wait for later versions which have been further developed. Also, the fact that devices that support 5G are not yet widespread, is a factor to take into account. According to Ericsson (2019), it indeed makes sense to go for standalone 5G, for those operators that wish to go for specialized services, whereas those that wish to offer high-speed connectivity might initially be better off with non-standalone. Given that the markets for specialized services are only now emerging, this obviously creates difficulties in the decisions that an operator must make.

Apart from this difference in 5G network architecture concerning the operator, there is also a move going on in which parties opt for private enterprise networks. Interviewees mention how for instance the automotive industry in Germany is moving to private networks for their factories (e.g. Enterprise IoT Insights, 2019). These private networks are built by the technology vendors from which operators currently source their network equipment, such as Nokia, but there are also other parties which are moving into this business, such as Siemens. Despite this seeming like a threatening situation, especially for those operators wishing to create specialized services, interviewees do not necessarily see it as such. First of all, this development is currently not very vivid in The Netherlands. More importantly, according to the interviewees it requires very specialized knowledge to set up these private networks. And according to one interviewee, this is simply something that the Dutch market is lacking. Operators on the other hand, are experts in network infrastructure, which is why they are currently confident that they will be the ones best able to provide those functionalities for specialized services. That said, interviewees also admit that this can indeed be a challenging situation.

Finally, important alternatives in the architecture can also follow from the fact that some companies are currently involved in developing connectivity platforms. The idea behind these platforms is that they are meant to integrate the connectivity services of the network operators. By doing so, customers can source their connectivity services from such a platform, instead of directly through the operator. The implication of course, is that connectivity is offered independent of the operator. In other words, if operator A is unable to provide the service to a customer's liking, then in theory this customer should be able to easily switch through that platform.

Besides these architectural alternatives, there are also quite a few other forms of connectivity, such as Wi-Fi, Narrowband IoT, LoRa, LTE-M, Bluetooth, and so on. All these forms have their pros and cons, which is why interviewees are expecting to see a mix in connectivity for at least the next decade. That being said, interviewees are quite convinced of the value of 5G, given that it offers more options with more functionalities.

Concluding

So, summarizing, due to these new functionalities, and the changes that are being made in the infrastructure, individualized service offerings to customers are becoming a possibility. So first of all, due to an increase in the quality of the services that can be offered, all sorts of new applications are becoming possible, which is the generative nature of this technology. However, as was established previously, in order for something to be truly generative, it is just as important that those developing the applications, or the complements, can easily connect to the underlying architecture. For this reason, the next section focuses on the modular nature of the technology, and looks specifically to the couplings between the operator's network, and the services that can be developed on top of it.

4.1.2 Modularity

As was established in Chapter 3, modularity follows from standardized interfaces between distinct components. Logically, this can both happen within the network, and between the network and the service. For instance, one might have separated components within a network with clear interfaces between them, yet very poor couplings with the services which that network should support. From architectural whitepapers such as the one by 5G PPP (2019), it appears that 5G networks aim to become much more simplified and modular. Virtualization and 'softwarization' separates the physical part of the operator's infrastructure, with those parts that run on the cloud (Oughton, Frias, van der Gaast, van der Berg, 2019). This separation allows operators to easily scale their network, enabling them to adapt to changing demand. Furthermore, the network of an operator is also simplified through concepts such as the separation of the user plane (i.e., the actual path which the data follows) and the control plane (i.e., the part which specifies the path which the data must follow), and through dividing network functions into components (Huawei, 2016). So, in terms of the modularity within a network, it indeed seems to be the case that 5G promises to develop standardized couplings between the individual components of a network.

Next, many of the interviews focused on the couplings between the network of an operator, and the specialized services that can be realized on top of them. The results of these findings are summarized in Table 3. A first interesting insight, is that many of the integration projects that are currently done, are very complex. One interviewee very clearly described how these projects go in detail, and how they can cause a lot of misery in the operations of an operator, how they cost a lot of time, and a lot of money. That is, these are highly customized projects, and integration requires coordination with not only departments within the operator itself, but also between suppliers of other software editions. In general, other interviewees also confirm that many of these projects, for providing specialized services such as mission critical communication (i.e. guaranteed communication), are highly complex.

Construct	Description
Coupling with complementary services	
Specialized services are currently very complex	Currently many specialized service projects require very complex integration with the network of an operator.
5G technology promises to make couplings easier	Through the use of a host of the new technologies that 5G offers, the couplings between a network operator, and the developer of a service, are supposed to become much easier.
Implementation for specialized services also causes difficulties	Respondents anticipate that the implementation of 5G will be a massive task for operators.

Table 3: 5G modularity

Now, according to both the interviewees and industry whitepapers, one of the things which 5G promises, is to make these couplings much more easy. One of the key components for this is network slicing. Interviewees mention how using virtualization and software defined networks, to create logically separate networks tied to individual users, should theoretically relieve many of the pains that are currently experienced. That is, due to the logical separation, the need to coordinate integration projects with other aspects of the operator's network disappears. Furthermore, the standardization body 5G PPP (2019) also describes how part of the 5G network architecture is focused on enabling cooperation between network operators and those outside the network, through APIs, standardized interfaces and protocols, and indeed again through virtualization or cloud based networks (Huawei, 2016).

Despite these promises, there will also be difficulties in implementing the technologies to be able to facilitate the couplings between the network and the service developer. That is, some interviewees highlight their concern that the implementation of these new technologies, will have significant impact on the organization of an operator. For instance, consequences can be that an operator needs to create new departments for certain management functions, and hire new people. Furthermore, interviewees clearly state how creating these new capabilities inside your network is simply an extremely complex job.

Concluding

Despite the reservations, the message remains that the theoretical promise of 5G is very big. This is an important one, as it means that theoretically it indeed becomes possible to create a modular architecture with standardized interfaces between the network of an operator, and the services that are created on top of it. By that logic, it indeed becomes possible to tap into the generative nature of 5G network technology.

4.2 Market architecture

Having described the technical architecture, the attention now turns to the market architectures that are forming around innovations relating to 5G. It was described that there are many different applications that are currently being researched or developed. The implication of this high amount of potential 5G-related applications, is that there are many potential market architectures to study, as typically each individual proposition is seen as being tied to a market (Ozcan and Santos, 2015). Since a 5G strategy for telecom operators should not just account for a single application, but instead take into account the variety of potential applications, it was decided to study market architectures on the aggregate level. For this aggregate of the market architecture, first the different roles will be discussed.

Roles have been defined, based on the types of organizations that are currently most vivid in the market interactions that are taking place. After discussing which actors can be discerned, a characterization of the current market interactions among these actors will be given, by means of describing the market interfaces among them.

4.2.1 Roles

Within the market architectures, there are multiple roles discernable. From the interviews a clear image emerged of which actors are currently the most important ones, in the market interactions that are taking place, in the context of 5G-related innovation. These actor groups are the operators, the business sector aiming to create value with 5G, and the municipalities and governmental organizations. There are some other actors that are also important, such as technology providers from the telecom sector. However, it was chosen to elaborate on these three, as these are the actor groups which are most deliberately shaping 5G-related innovations in The Netherlands.

Telecom operators

The first important actor, is the telecom operator itself. In the introduction, the position of the operator was characterized as one which is potentially problematic, due to uncertainties about value creation and appropriation, and serious investments being necessary to deal with exploding demands in data. This section now focuses on characterizing the current state of the operator. These characteristics are presented in Table 4.

Construct	Description
Momentum	
Ambition to be critical	In general, operators have the ambition to become a critical part in the innovations that are based on 5G.
Convinced that 5G will lead to value	Operators are convinced that 5G will lead to value, both in existing environments, and in new environments.
Finding out where there is value	Operators are currently in the process of researching what value can exactly be created with 5G in the Dutch market.
Focusing on bringing 5G to the market	Operators are currently in the process of preparing for 5G deployment, and already building some 5G capabilities in their network.
Setting up fieldlabs	Operators are setting up fieldlabs to research where the value of 5G lies, and to experiment with new propositions.
One network to rule them all	
Dedicated to selling SIMs	In general, an operator's sales processes are focused on selling SIM cards.
Not really prepared for specialized services	Currently, specialized services such as complete reliability, require much manual work, mostly in the core network of an operator. This makes it often unfeasible for an operator to pursue.
Organized for connectivity	The general focus of an operator is on providing connectivity.
Organized for network availability	Related to providing connectivity, another key focus of an operator is on ensuring that the network is reliable.
Organized to serve mass	Operators are organized to serve the mass consumer market. This means that services are standardized, and best effort.

Value creation is left to the customer	In accordance with the focus being on providing connectivity, the value creation part is typically left to other parties.

Table 4: Characteristics of the telecom operator

Momentum

Firstly, there currently is quite some momentum within the operators' organizations around 5G. Operators state that they are convinced that 5G will lead to value by making many new applications possible, and they want to play a role in that value creation. Furthermore, they see these developments as a means to appropriate value. For this reason, they are currently focusing on bringing 5G to the market, and they are researching where exactly the value of 5G lies, for instance through developing and testing applications in fieldlabs that have been set up across The Netherlands. Finally, this momentum is also recognized by other parties. They see that operators have the ambition to be important in the new generation of applications, that operators are trying to develop the demand and the markets for 5G, and that operators are interested in initiatives that are sprouting up in cities.

One network to rule them all

Another theme which emerged from the interview data is that the typical operator is a large organization, focused on achieving operational efficiency. The operator is good at building and maintaining large communication networks for the mass consumer market, or as interviewee 16 labeled it: "one network to rule them all". For this purpose, interviewees state that operators are completely organized for connectivity, network availability and coverage. This in turn implies that the typical operator has strict targets in multiple departments. The technical departments are completely dedicated to meeting its targets to ensure high network availability. The same goes for sales departments, with people dedicated only to selling, and being judged only on the number of sales that they make. In other words, the organization of the operator is said to be completely tuned to selling SIM cards.

The result of this focus on the consumer, and therefore on deploying and maintaining complex networks, is a large organization with many dependencies inside it. Interviewee 1 explains how often projects in the organization of an operator can be interrelated:

> "… what I am telling you now, is actually what happened. This is actually what happens at an operator. So, very often there are projects that are in each other's way. We once made a list, when we were in such a trajectory with the technology provider, and we had a meeting in Eindhoven with some other projects. And in that meeting, we identified 23 projects that in some way were dependent on each other. Some were in the core network, some in a node, others in the optical fiber, others in the optical fiber transmission equipment, others in the IP, routers and switches, others in the area of radio and software, others in the architecture. So, the entire coordination of those projects can be crucial. It was also crucial in that project of ours. And if we had not done that, then we had never met our target, but also those other projects that were interdependent."

Similarly, malfunctions in new software can have strong impacts on the entire network, and this is why the operator is very risk-averse regarding projects that can have an impact on their network. For instance, to offer guaranteed services (i.e., guaranteed connectivity) instead of best effort services, integration with the network of an operator is necessary. However, this is labelled by one interviewee as very complex, and an operator will only accept this when they can absolutely guarantee that it will not negatively affect their network. The result is that network integration projects are subjected to extensive testing protocols, coordination with the entire organization of an operator, and legal discussions. In addition, the operator generally expects those parties they cooperate with, to truly understand the language of the telecommunications world. As interviewee 1 explains it through an example:

> "And if I'm a start-up, well, then they already give you a nasty look, because then you don't know what you're talking about."

So, the conclusion is that currently, the organization of an operator is not truly prepared to deal with the specialized services that come with 5G. As covered in the technical architecture section however, it is exactly in these areas that 5G makes promises.

Municipalities

The second actor group are the municipalities. Municipalities of larger cities take a dominant role in this stage of the market formation, since larger cities are among the first places where 5G will be introduced. Furthermore, to deploy 5G, coordination with cities is necessary. The characteristics of the municipalities' stance regarding 5G, is presented in Table 5.

Construct	Description
Momentum	
A lot is happening around innovation	Many municipalities are focusing on the topic of innovation, seeking ways to stimulate it and developing their own city-specific propositions.
Wanting to create or maintain leadership	Municipalities see 5G as one of the technologies which allows them to create or maintain a leadership position when it comes to technology and innovation.
Parties are coming together	Parties within the municipalities are coming together, which are all interested in innovation activities relating to 5G.
Wanting to contribute to 5G developments	Municipalities want to see how they can contribute to developments around 5G, for instance on how to deploy 5G in a city.
Stimulating innovation	
Bringing organizations together	To stimulate innovation, municipalities see the bringing together of motivated organizations, as one of their key roles.
Let the market experiment	Municipalities want to facilitate innovation, by giving the market the space for experimentation.
Providing an infrastructure	To stimulate innovation, municipalities see it as their role to provide a common infrastructure, of which connectivity is an important part.

Table 5: Characteristics of the municipality

Momentum

First of all, similar to the telecom operator, there is momentum around 5G innovation from the position of municipality. In many of the larger cities there are programs around the next generation of connectivity, around smart cities, digitalization, and so on. Interviewee 13 remarked how there were many things happening in his city, and how eager they were to do more:

> "We also do things with smart mobility, with our traffic lights for instance, they remain longer on green for our cyclists. … And we also use LoRa sensors for measuring the parking pressure.

> And on industry parks we measure how long trucks are standing there; because they can't stand there any longer than half an hour, and it's very difficult to measure that. So for that we also use LoRa sensors. So, a lot is happening. And for us, it is the more the better."

Furthermore, cities typically see these new technology waves, as ways to create or maintain a leadership position. One municipality wanted to become the 5G city of Europe, whereas another municipality's economy is strongly tied to technology, which is why they want to maintain their leadership. Municipalities are also focusing on bringing organizations together, which shows the positive energy that is going on. Finally, municipalities are researching how to 5G can be installed in cities, which also shows a level of dedication to the next generation of mobile technology.

Stimulating innovation
In general, municipalities want to stimulate the economic activity in their region. According to them, a key way to achieve this, is through stimulating innovation. For this purpose, municipalities aim to play a facilitating role, by bringing willing organizations together, by offering space for the experiment and letting market parties develop propositions, and by providing an infrastructure. According to interviewees, this infrastructure also includes connectivity functionality, for which 5G is one of the options.

Business

The final group of actors come from the business world. This includes all sorts of organizations, such as harbors, factories, technology companies, and technology startups. There are a few characteristics which unites these companies, and these are presented in Table 6.

Construct	Description
Momentum	
Companies are developing propositions based on 5G	Companies are actively developing concepts which are based on 5G technology.
Companies are interested in 5G programs	Companies are eager to join 5G programs and fieldlabs.
Companies see 5G as a means to innovation	Companies see 5G as a relevant and promising technology, allowing them to develop new types of innovations.
Future potential	
Digital and automated environments	Companies see 5G connectivity as a means to digitalize and automate their existing environments.
New environments and situations	The expectation is that the 5G-related digitalization will unlock a wave of completely new-to-the-world applications.

Table 6: Characteristics of the business sector

Momentum
First of all, like with the operator and the municipalities, there seems to be momentum within the business world around 5G innovation. While the amount of momentum is more uncertain, since interviews did not give an indication of the amount of companies that are involved with 5G innovation, there still appears to be quite a lot of activity. In many regions businesses are interested in local 5G

programs. Furthermore, companies are developing concepts and propositions based on 5G, among others within these 5G pilot programs. Finally, companies see 5G as one of the technologies based on which interesting new value propositions are going to be developed.

Future potential

Strongly relating to this momentum, is the reasonably clear vision that the business world has of the future. Respondents see a future in which existing environments are completely fitted with sensors. From these sensors, digital twins of the real world can be created. When applying AI on these digital images, all kinds of processes are bound to be completely optimized. Furthermore, when robotics are implemented as well, all sorts of environments, such as factories and harbors, could theoretically be completely automated. This combination of AI, robotics, and the connectivity necessary to support massive amounts of sensor data, is in fact what one respondent labels as the combination which will make the 4th industrial revolution succeed. So, the vision that these respondents have, is one of an automated version of the existing world, that is, fully automated factories, ports, agriculture, and so on. Apart from this rather clear vision, it is also acknowledged that many of the future value propositions are still beyond our grasp. Such new-to-the-world propositions might for instance be the often mentioned example of surgery on a distance.

4.2.2 Market interfaces

Since the described actors are the ones who currently lead the developments regarding 5G innovation in The Netherlands, there logically are a number of interesting interactions among them. As has been pointed in the theoretical background chapter, these interactions represent the market interfaces that are emerging between these actors (Jacobides et al., 2006). In turn, these market interfaces are the mechanisms through which actors interact. As such, this section aims to describe the emerging market interfaces, according to the mechanisms which govern the interactions among market actors.

Cognitive elements

In the previous sections it was noted how for every actor group, there are different reasons why they are motivated to engage in 5G-related innovation. This momentum obviously positively influences the interactions that are taking place in the market. However, there are also a number of cognitive elements which have a more negative, or limiting, effect on the interactions between actors. These elements are presented in Table 7.

Construct	Description
Concerns	
Fear of making mistakes	When it comes to big innovation projects, people are afraid of making mistakes in investing time and resources.
Related to job changes	People see 5G, with its promises of digitalization and automation, as a threat to their current jobs.
Focus on health risks	There is a significant group of citizens which sees 5G as a technology that can cause health problems.
Privacy concerns	There are multiple 5G-related innovations and parties, which generate privacy concerns.
Lack in understanding	

People do not fully understand 5G	People do not understand exactly what 5G is, what it will offer to them, and how it is different from other connectivity solutions.
People do not see the need for innovation	People often do not see the need for innovation, and need to be convinced.
People do not understand the costs of specialized connectivity	People do not understand how certain specialized services, require a lot of resources and investments on the side of the operator.

Table 7: Cognitive elements of the market interfaces

Concerns

Firstly, many interviewees state how individuals have concerns regarding 5G technology. One interviewee explains how individuals and organizations in his environment are hesitant to participate in larger, 5G-related innovation projects, out of fear of making poor decisions. This is because these projects require a lot of time and resources, and because they can have big impacts on existing environments. Secondly, interviewees mention how individuals are typically afraid to lose their job, or to see their job massively changed, due to 5G-related innovation. These fears are understandable, for example when one takes into account that many of these projects are about automating existing environments. Furthermore, there is also a significant group of citizens who are afraid of the health risks which they assume that 5G brings along. Interviewees from municipalities explain how citizens continuously express their concerns, and sometimes quite fiercely. Therefore, this may well be a factor that can shape the future interactions in the Dutch markets. Finally, there are some 5G-related privacy concerns. First, there are those innovations which make use of continuous video recording in public spaces, so there are individuals who express their concerns about how privacy will be ensured. Furthermore, the politically sensitive company Huawei is one of the three big technology vendors of 5G technology. Interviewees state how there are many individuals who fear that doing business with Huawei might put them at risk of Chinese government involvement.

Lack in understanding

Besides these concerns, there is also a general lack in understanding when it comes to 5G-related innovations. First of all, most people do not understand exactly what 5G is. People do not know exactly how 5G is not just more 4G, but actually different. People do not know what these differences can mean for them, which sorts of value propositions they make possible. Furthermore, people do also not know how 5G is different from connectivity alternatives such as Wi-Fi or LoRa, or why exactly one would either use a private 4G/5G network, or make use of an operator's services. Closely relating to this, people also do not understand why specialized services from an operator cost so much money. Interviewees explain that this is in part due to what consumers are used to pay for their mobile subscriptions, and also in part due to them not understanding how difficult it is, technically, for an operator to provide guaranteed services. Finally, one interviewee extensively explains how people often simply do not see the need for innovation projects. This for instance happens, because people are unaware of the dependencies that they have within and between organizations, and are unaware about how managing these dependencies could save them money, or generate it.

Structural elements

Apart from the cognitive elements which influence the interactions of actors, there are also a number of important structural elements. These are presented in Table 8.

Construct	Description
Dependencies	
Dependencies	For many of the 5G-related innovation projects, there can be many dependencies governing interactions.
Unique complements	
Unique complements	There are many 5G-related innovations, for which there unique complements.
Goal differences	
Stimulating innovation	Some actors, such as municipalities, see 5G as a means to stimulate innovation.
Bringing 5G to the market	Actors from the telecom sector focus on bringing 5G to the market.
Differences in speed	Typically, government parties move slower than market parties, due to goal differences.
Commercial interests	Actors can have strong profit motives
City themes	Municipalities typically focus on societal, or city-specific themes.
Finding out what 5G can mean	Some parties engage in 5G innovation, to find out what 5G can mean for them in the future.
Interactions bound by sociotechnical systems	
Existing connectivity networks	There are many existing forms of connectivity, which will not simply be discarded by companies that currently make use of them.
Existing price structures	Existing price structures shape the expectations of actors for 5G-related services.
Existing spatial arrangements	Cities are spatially arranged in ways, such that they shape the ways in which 5G can be implemented.
Existing technology systems	Actors are embedded in current technology systems (e.g. specific machinery), which shapes the types of innovations they can currently pursue.
Legislation	For many of the 5G-related innovations, legislation shapes what actors can and cannot do.
Market rules	Existing market rules govern the ways in which actors interact.
Spectrum availability	The availability of spectrum determines whether 5G can be deployed.
Initial phase	
Creating proof of concepts and pilots	Organizations are still in the phase where they are developing proof of concepts, and pilots.
Finding out where there is value	Many organizations are currently focused on finding out where exactly value from 5G comes from.
Negotiations are emerging or not yet taking place	Concerning value appropriation, in many cases negotiations are not yet taking place, or only emerging.

Propositions are not brought on the market yet	There are not yet any 5G-related innovations which have been brought onto the market.
We are at the beginning	Interviewees literally state that we are still at the very beginning of 5G-related innovation.

Table 8: Structural elements of the market interfaces

Dependencies and unique complements

A first important factor which influences the interactions of actors, is the presence of dependencies. That is, for many of the innovations, organizations depend on other actors, directly or indirectly. The implication is that often collaboration is needed. Closely relating to this, is that for quite a few of the 5G-related innovations, there are unique complements. As has been described in the theoretical background, unique complements are those components which are a prerequisite for a system to function. For instance, one interviewee describes how in order to automate a factory, one needs connectivity such as 5G, robotics, and AI. Without these, the whole concept does not function. As one respondent states, this complementarity partly comes from the digitalization of environments. That is, in many of our existing environments, digital elements are added to improve or automate existing processes. This almost necessarily creates a world in which no party can do it alone.

Goal differences

Previous sections have already described some of the specific goals that actors have. These goals can coincide, facilitating collaboration, but interviewees describe how goals can also differ, thereby making interactions more difficult. One interviewee gave an example of this, as there were parties with strong short-term profit motives, whereas his organization's goal was to focus much more on long-term explorative innovation.

Interactions bound by sociotechnical systems

Just like interactions depend on others, interactions also depends on the states of existing sociotechnical systems. Firstly, organizations make use of currently available connectivity solutions, such as 4G, Wi-Fi and optical fiber. One interviewee elaborates on how factories that have recently introduced connectivity solutions based on optical fiber, will not simply go ahead and dismiss that solution for new expensive 5G technology. Likewise, the same goes for other technology systems, such as specific machinery used in a factory.

Interviewees also describe how existing price structures can govern interactions in the telecom world. As stated before, people let what they pay for mobile subscriptions, govern their expectations for price structures in the business world. One interviewee elaborates on how specifically this issue, has made developing connectivity solutions in the Dutch business world very difficult.

The spatial arrangement can also be an important issue. Interviewees describe how cities are arranged in certain ways, which can complicate the deployment of 5G. Furthermore, legislation can be a crucial issue, with interviewees giving multiple examples on how legislation slows down certain innovations. Simultaneously though, one example is given on how a legislative proposal might speed up 5G deployment, as this proposed law would obligate municipalities to make available their public infrastructure (e.g. street furniture), to operators.

Market rules also govern interactions. One interviewee describes his organization's market as very conventional, with organizations operating based on being part of each other's personal networks, and innovations only succeeding when their success is absolutely guaranteed.

Finally, in the markets of 5G, a crucial structural element which governs interactions is the availability of spectrum. The Dutch market is slow in this aspect, and interviewees are concerned about the fact that The Netherlands will lag behind in network speeds in the next few years. The lack of available spectrum can then hamper innovation in the Dutch market, relative to innovation in other countries.

Initial phase

The final structural element which governs the interactions, is that these market architectures are still at the very beginning of their formation stage. Propositions have not been brought on the market yet, negotiations over value appropriation are not yet taking place and actors are still finding out where there is value. The implication is that most interviewees claim that the focus does not yet really lie on competition. Instead, interactions have a very exploratory nature, with many interactions taking place in fieldlab settings, where the overall mindset is that everyone participates and collaborates.

4.2.3 General market structure

The above sections have described the technical architecture, the most important actors in the market, and the interactions or interfaces among them. To conclude this section on the market architecture, a general overview, of how the market looks from the perspective of the operator, is given. This is graphically presented in Figure 7.

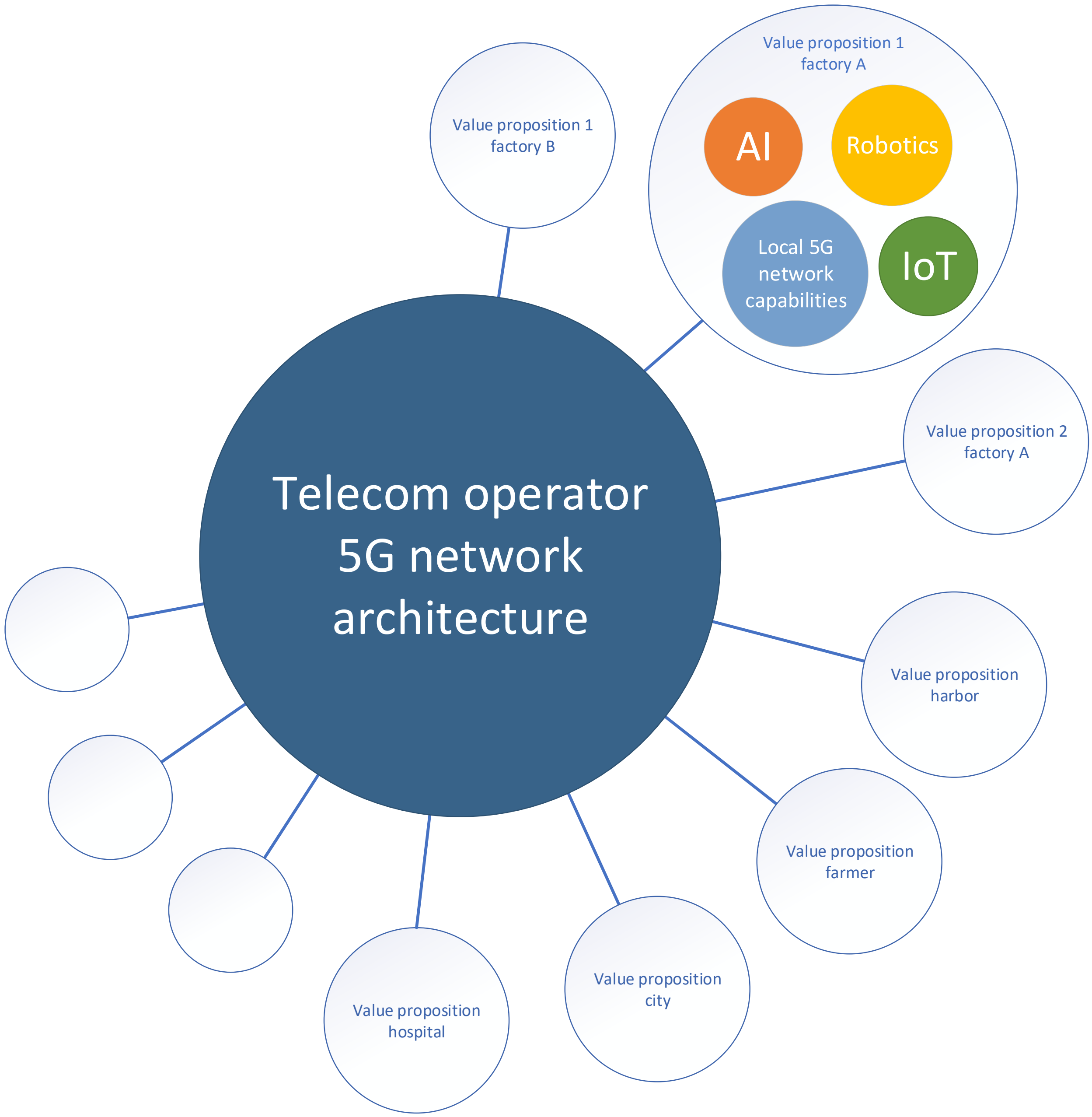

Figure 7: Market architecture from the perspective of the operator

The above figure aims to represent the nature of the market, from the perspective of the operator. First of all, the generative nature is represented. Based on 5G, all sorts of value propositions will be possible. Applications that are currently being thought of include creating digital twins of factories for the purpose of automating them, equip the city with sensors to tackle parking problems, automating processes in harbors, VR-based applications for consumers, and so on. For all these value propositions, there typically are some important unique complements. The example of an automated factory was give, which requires AI, connectivity, sensors and robotics. Finally, each value proposition effectively has its own market architecture, and therefore its own market interfaces. For this reason, one must consider the abovementioned interaction characteristics, for each individual value proposition.

4.3 Uncertainty

Based on the characteristics of the technical- and market architectures, a number of uncertainties can be identified. The most important ones are presented in Table 9.

Construct	Description
Alternatives	
Alternative 5G architectures	Uncertainty arises from the multiple possible 5G architectures, such as private networks, and networks from operators.
Alternative connectivity solutions	Uncertainty comes from the multiple forms of connectivity, such as 5G, Wi-Fi, and LoRa.
Many future alternative solutions	There are many potential solutions based on 5G technology, which leads to uncertainty about which solutions will become successful.
Market uncertainty	
Business model uncertainty	There is uncertainty about which business models operators should employ.
Strategic component uncertainty	There is uncertainty about which components will strategically hold most value, for future value propositions.
Timing uncertainty	There is uncertainty about when exactly the potential of 5G will be unlocked.
Value appropriation uncertainty	Operators are currently uncertain about how they will appropriate value from 5G-related business innovation.
Value that can be created	There is uncertainty about what value can be developed based on 5G, and how exactly this can be done.

Table 9: Uncertainty

4.3.1 Uncertainty from alternatives

First of all there is uncertainty which comes from all potential alternatives. There are multiple possible architectures for a 5G network. Historically, the common solution is where the telecom operator deploys nationwide networks. However, as described in the technical architecture section, there is also the possibility of creating private 5G networks. Furthermore, according to interviewees, there are also ongoing developments, in which platforms are being developed which could impact the network architectures in such a way, that propositions based on 5G could be developed independent of the operator's network. Apart from the architectural alternatives, there are also alternatives in the type of connectivity. That is, actors can choose for connectivity forms such as 5G and Wi-Fi. Finally, there will be many future alternative value propositions. Due to these many alternatives, it is uncertain which ones will become successful. That is, there is uncertainty about which value propositions will be successful, and what the exact nature of the market- and technical architectures will be. As described in the theoretical background, these uncertainties are also typical for generative technologies which find themselves in initial market phases.

4.3.2 Market uncertainties

Interviewees also named some other uncertainties, which in turn can be explained in terms of the market characteristics described earlier. First of all, it is uncertain what value can be created exactly, and how this can be done. As specified before, individuals have trouble understanding 5G, which explains how they have difficulties in understanding what types of complementary services can be created, based on 5G. Furthermore, it was established that existing sociotechnical systems, and unique complements such as other technologies, influence what can be done in regard to 5G. As such, understanding the value that can be created, requires a thorough understanding of all these factors, which in turn explains why there is uncertainty in this regard. This is also typical for an initial market phase, in which the structural and cognitive processes leading to stable markets still have to play out. Based on these same factors, it can also be explained why interviewees find it difficult to determine how value can be appropriated, which business models should be adopted, and which components will hold the most strategic value.

4.4 Dynamism

Despite the fact that this thesis covers only a snapshot perspective of 5G-related developments, the interviews uncovered some dynamics relating to the market- and technical architectures of 5G. These are presented in Table 10.

Construct	Description
Adoption processes	
Availability of spectrum will take a while	In The Netherlands, the completion of spectrum auctions will still take a while, which is why spectrum will become increasingly available.
Evolutionary processes	Innovation will depend on combinations of increasing possibilities.
Intermediate solutions will be created	Innovation depends on what is possible in the current system.
Operators will prioritize investments over time	Operators will invest in network capabilities based on priorities and differentiation.
Technology needs to be developed further	5G technology has not yet been fully developed.
Increasing clarity	
Dynamically discovering possibilities	During innovation projects, actors discover what is possible with 5G.
Standardization processes	Standardization processes of 5G are ongoing, and make increasingly clear what the technology will look like.
Momentum dynamics	
Clarity leading to momentum	Clarity on what can be done, and what actors' intentions are, leads to momentum around innovation projects.
Internal momentum leads to external momentum and vice versa	In innovation projects, momentum from the perspective of a focal actor leads to momentum at its partners, and vice versa.

Uncertainty leads to a decrease in momentum	Uncertainty about what is going to happen or can be done leads to hesitation and a decrease in momentum.
Move toward collaboration	
Organizations believe in collaboration	Interviewees state that their organizations believe more in collaboration than in competition.
Unique complements require organizations to collaborate	Due to the presence of many unique complementarities, actors will have to collaborate for many of the future value propositions.
Strategic components change over time	
Applications and devices became revenue generators	At a point in time, applications and devices took over the telecom business, as the most valuable components.
Connectivity may become a bottleneck again	One interviewee states how we will become increasingly dependent on connectivity, which might enhance its strategic value.
Data became commodity over time	Historically, data went from being a good revenue generator, to a commodity.
Latency is the new speed	One key aspect of 5G, latency, is believed to become crucial for some future value propositions.
Platform market is the future	Platforms which allow propositions to be developed independent of operators, are believed to be a key future component.

Table 10: Dynamism

4.4.1 Adoption processes

Interviewees are quite convinced that there first might be a long adoption period before the full potential of 5G can be realized. First of all, this is for a large part ascribable to the notion that existing systems influence the solutions that can be developed. One can see this for example in the development of autonomous vehicles, both cars and boats. That is, there are currently those that envision a future situation in which vehicles will connect with each other, based on which then vehicles can respond real-time to each other’s input. However, this would require both connectivity everywhere, and guaranteed network service all the time. Since this is currently not the case, autonomous vehicles will at least for now not critically depend on communication technology. That is, solutions that are currently being developed will be based on local AI:

> “Okay, let’s put it like this, when I talk about autonomous driving, then I’m talking about a car that can drive on its own, for which it does not necessarily need connectivity.” (Interviewee 10)

Due to these existing systems, it is to be expected that many intermediate solutions will be created, before systems can develop toward realizing the full potential of technologies like 5G. In terms of autonomous harbors, this would for example mean that with first versions of autonomous ships, the harbor master would take control over these boats inside the harbor. As interviewee 10 explains:

> "And you can say: a ship can sail autonomously and that's safe enough, so in principle we do not need this intermediate step. But that intermediate step will definitely be incorporated in the entire process, because that is a strong demand of the harbor. Because laws and policies are also entirely tuned toward that current situation, to the current system."

The same is to be expected regarding communication solutions. As mentioned above, there are many organizations who have invested in solutions based on glass fiber, Wi-Fi, or LoRa, and these organizations are not immediately going to adopt a new standard, for which their entire communication infrastructure might need to change. For this reason, interviewees are convinced that in the next ten years, there will be a connectivity mix, with different types of applications and businesses, adhering to different connectivity standards.

In turn, because solutions depend on existing systems, there will be an adoption period, before the full potential of 5G can be realized. That is, all sorts of systems have to adapt and evolve before that can happen. A good example is the autonomous vehicle. In creating self-driving vehicles, it is not just about creating a vehicle that is capable of responding by itself to its environment, and drive automatically. It is also about changing legislation, changing infrastructures, developing ways of testing autonomous vehicles, rethinking the concept of a driver's license, and so on.

4.4.2 Increasing clarity

Another dynamic which was concluded from the interviews, is that during 5G-related innovation projects, there is increasing clarity about what can be done with the technology, and what actors can do to complement each other. Furthermore, 5G is built around standardization processes. These processes are ongoing, and make it increasingly clear what is possible with 5G.

4.4.3 Momentum dynamics

Momentum was found to closely relate to clarity. That is, an increase in clarity about what it is that can be created and will be done, leads to increases in understanding of the concept, increases in enthusiasm, and therefore increases in momentum. Furthermore, similarly to Dattée et al. (2018), interviewees indicated how in their innovation processes, momentum from their own organization led other external organizations to increase their involvement, and vice versa. Finally, it was also found that uncertainty can lead to hesitation among project actors, and therefore a decrease in momentum.

4.4.4 Move toward collaboration

It is assumed that there will be an ongoing move toward collaboration. Firstly, some organizations state that they simply believe more in collaboration, than in competition. More importantly however, this move is believed to be necessary, due to the unique complements that are present in 5G-related business innovation. As interviewee 14 states:

> "We are a telecom operator, so we have no understanding of transport and logistics, or about healthcare, nor about agriculture. However, we do see that digitalization is taking, and going to take, place in those environments. So we very much seek those interactions with these actors."

4.4.5 Strategic components change over time

For the telecom market, it has been true as well that strategic components have changed over time. Historically, connectivity, or data, used to be a very strong revenue generator. Over time that has changed however, and nowadays it is more or less seen as a commodity. At one point, the device, and the applications that could be used on it, together with the operating system, took over as strategically more valuable components in the telecom markets. Some interviewees believe that in the future, it will be devices and applications as well, that will reap the most benefits. However, others state that it may very well be viable that other components will take over as strategically most important. Regarding 5G technology, latency is seen as a key component, which may become crucial for many propositions. One interviewee states how connectivity may in general become very important again, for all sorts of business and societal applications. This might then lead to connectivity becoming a strategic bottleneck again. Again others state how platforms that allow propositions to be developed independent of operators, will be the future, by reshaping the industry architecture. All that can be concluded here, is that the vastly different nature of future value propositions, might indeed cause again a change in which component will be strategically most valuable.

4.5 Capturing and creating value

Having described the empirical context, this section will now describe how operators should strategically act, based on empirical findings. The findings are summarized in Table 11.

Construct	Description
Increase modularity	
Increase modularity	Modularity is increased through employing 5G technologies, and through developing connectivity platforms.
Collaboration	
Collaborate directly with complementors	Operators collaborate directly with complementors in creating value propositions, through developing their network capabilities such that these connect to the complements.
Collaborate with those that create interfaces with other complementors	Operators also collaborate with intermediary actors, who specialize in creating modular interfaces between the network of an operator, and the complementors.
Focusing only on connectivity and collaborating with others	Operators focus on excelling in their components which is providing connectivity, and focus on collaborating with the providers of complements.
Understanding the customer's needs	Part of collaboration with complement creators, is understanding truly what they need, as often specialized services are required.
Finding partners	
Finding partners	To stimulate complementary activity, partners should be attracted.
Using internal complements to showcase potential	
Using internal complements to showcase potential	One operator mentions how complements can be built, to showcase to complement developers what is possible, and how complements can be built based on the network.
Exerting dynamic control	

Influencing	Operators should influence complementary actors in following the paths that they envision.
Monitoring	Operators should continuously monitor their environment to track whether everything runs according to their envisioned futures, and whether important changes are taking place.
Updating	When changes are taking place, strategies, envisioned futures, and actions should be adapted to influence the environment to the benefit of the operator.
Innovating in controllable steps	
Automating existing processes	Attention is currently focused on creating services which automate existing processes.
Innovating in controlled environments	Innovation activities are conducted in environments in which the amount of dependencies can be controlled, such as in fieldlabs.
Keeping innovations controllable	By starting with minimum viable products, or by taking small trial-and-error steps, innovations can be kept controllable.

Table 11: Value creation and appropriation

4.5.1 Stimulating modularity

The first category which can be discerned, is that operators are currently focusing on stimulating modularity. Operators do this through a number of ways. First of all, there are the 5G technologies which have been described, such as network slicing, software defined networking, and edge computing, which allow the network of the operator to become more modular, and deliver specialized services easier to complementors. Secondly, there is also a move in which connectivity platforms are being developed, which allow propositions to be developed that can operator independent of operator. As such, complementors can easily connect to connectivity networks, without having to take into account whether their services will work on every operator network. Finally, there is also one operator who works together with intermediary parties, that integrate the network of the operator with complements, which then allows specialized services to be created based on the network of an operator. These intermediaries are described to focus on specific markets, and as having specialized skills. Since the operator does not have the resources to do all these integrations by themselves, this allows the operator to connect to a much larger market of nongeneric complements. Through making use of these intermediary parties, the operator therefore makes the connection between their network and the nongeneric complements, more modular. Based on these findings, the first researched-based design proposition can be updated to the following:

1. In markets characterized by nongeneric complements (C), the FF should increase modularity, by employing 5G technologies such as network slicing, SDN, and edge computing, by means of technical mechanisms such as connectivity platforms, APIs and SDKs, through working together with intermediary parties that create modular interfaces with other complementors, through the use of standards, and through the use of social mechanisms such as incentives (I), since, through making it easier to develop complements, mobility in complementary assets will increase, thereby increasing competition in these complementary assets (M), which in turn will decrease the value of these complementary assets, relative to the assets where the FF is active, which in turn creates an architectural advantageous position for the FF (O).

4.5.2 Collaboration

As stated before, there is a general move toward collaboration. This has been found, to be partly due to digitalization, which has created a situation of unique complements, in which complementary actors do not have the capabilities to develop all the components of a value proposition. In this setting, operators deliberately choose to only, or mainly, focus on their part of the architecture, which is providing connectivity, and then collaborating with providers of complements. This collaboration however, is done in different ways.

Firstly, there is one operator who collaborates with intermediaries who integrate nongeneric complements with the network of the operator. This has been covered in the previous section, and it was argued that this increased modularity.

Secondly, there are operators who directly cooperate with complementors, by developing innovations in joint efforts. The idea that is leading here, is that operators should adopt principles of the co-creation of value. That is, whereas operators used to follow the principles of technology push, they are now convinced that instead value must be created together with the customer, allowing services to be based on a customer's needs. This idea of collaborating directly with cooperators, therefore closely relates to the notion that communication and interactions should be focused on truly understanding what it is a customer needs.

There are some important reasons as to why this type of collaboration is important. First of all, due to the assumption that operators cannot possibly develop all complements on their own, this way of collaboration enables them to gain access to complementary components. Secondly, these interviewees note how co-creation allows them to gather feedback on how to develop their services. Thirdly, interviewees state how through co-creation, they can decrease a degree of risk. That is, previously, operators would build their network, and then push their technology onto the market. The new idea of co-creating value, goes accompanied by an aim to only build certain parts of network capabilities when a customer desires them. So, apart from the general required investments in the network, these specific investments are only made, when specific network features are really needed. This in turn decreases the risk of investing in network assets that are not going to be used. This notion also closely relates to the momentum dynamics described by Dattée et al. (2018), and in section 4.4.3, where it was stated that increases in clarity about what needs to be done, and joint commitments of involved parties, lead to more momentum among the parties, thereby moving innovation projects forward. That is, having actors making commitments jointly, and only based on clear needs, creates momentum around a project, which allows a project to move forward, thereby increasing clarity again. Based on these findings, the design principle based on the component strategy, and the bottleneck strategy in crowded bottlenecks, can be updated to the following:

7. When following a component strategy, or a bottleneck strategy in a crowded bottleneck (C), the FF should focus on collaboration, specifically on co-creating value with complementors, and on innovation in both its collaborative aspects and its components (I), as this will let the FF be able to have access to complementary components, to improve its own services, to differentiate itself from other component competitors, and to reduce investment risk (M), which will allow the FF to create and appropriate more value (O).

4.5.3 Finding partners

The interviews highlight also how attracting partners is a critical issue in this phase of the emerging markets. According to interviewees, this is about attracting actors that are interested, and that offer interesting complementary ideas, simply by approaching them. Also, it is about building networks of these actors, as interviewees state that larger, collaborating networks, have value, in the sense that this creates more momentum, and gets things done. Finally, such larger networks of partners supposedly create mutual benefits, when partners recommend each other to others in the market. As one operator explains, when their customers or interested parties ask them for specialized services, which they do not develop themselves, but one of their partners does, then they happily recommend their partner's services. This indirectly then helps the operator, as growth of their partner helps them growing as well. Based on this, theory-based design principle six can be updated:

6. In the initial phase of a platform market (C), the FF should aim to attract interested third-party complementors, build larger networks of these interested parties, and build in-house complements (I), as this creates more innovative activity, reduces uncertainties related to the platform, opens up the opportunities for knowledge spillovers, creates incentives to innovate through competition, and creates incentives to help each other in generating business (M), which would then lead to a higher quality and variety of components, and a higher value of the platform (O).

4.5.4 Using internal complements to showcase potential

An important part of the sixth design principle, is to build complements in-house in the initial phase of a market, as this allows the FF to showcase what is possible with the platform, and how complements should be developed. Interviews did not broadly uncover this, as in fact only one operator shortly mentioned that this is something that they do. Therefore, the design principle will not be made more specific, but it should be stressed that indeed in these markets, operators should use such in-house complements, specifically for the stated purposes.

4.5.5 Exerting dynamic control

A number of interviewees also describes mechanisms which can be attributed to the dynamic control strategy of Dattée et al. (2018). Specifically, a number of interesting mechanisms were mentioned that will be covered here. First of all, multiple interviewees place great importance in the use of mechanisms such as roadmaps, development routes, or programs. These tools are specifically used to communicate with partners, allowing actors to monitor whether everyone is following the same plans, and to influence each other into focusing attention on desired areas. Another mechanism which is interpreted as crucial, is the showing of successful examples, to influence others, both internal and external to the FF, to move in desired directions. One interviewee explains how he tried several things, for instance giving lectures, which all did not work to convince his environment. Only when he was able to showcase some interesting successful examples, his environment became enthused. Based on interview findings, theory-based design principle 8, can be updated to the following:

8. In the initial phase of a generative technology in a layered modular architecture (C), the FF should exert dynamic control, by influencing and monitoring its environment, by employing mechanisms such as roadmapping and showing successful examples, and by updating its strategies (I), since through an increased ability to commit resources to the right applications, to

gain control over bottlenecks, and to make sure partners also keep committing to the right applications (M), the FF will be more able to create and appropriate value (O).

4.5.6 Innovating in controllable steps

A design principle fully based on practice, comes from the notion that 5G-related business innovations should not aim to overextend. First of all, interviewees advise that innovations should mainly focus on automating existing processes. Interviewees do expect that 5G-related innovation will lead to completely new types of value propositions. However, they also see that at this moment, a lot is to be gained from digitalizing and automating existing environments. Given that many of the envisioned 5G-related innovations are strongly embedded in assumed stable sociotechnical systems, it does indeed make sense to keep innovations controllable. That is, such innovations should be created in a combinatorial fashion, by taking into account and building upon the current systems, and addressing one factor at a time. Furthermore, interviewees explain how, since innovations often are dependent on many actors, it for now makes sense to experiment in controlled environments. This is why the use of fieldlabs is seen as beneficial, since in such environments the amount of dependencies can be limited. All considered, this creates the following design principle:

10. When innovations strongly depend on current sociotechnical systems, and these sociotechnical systems in turn are considered stable (C), the FF should engage in controllable innovation by focusing firstly on improving existing environments, engaging in combinatorial innovation, and by innovating in controlled environments (I), since through decreasing the complexity of innovation (M), this makes successful innovation more achievable (O).

4.6 Final set of design principles

Based on the practice based findings presented in this chapter, a final set of design principles can be derived. This has been done through a synthesis of research-based and practice-based design principles. The final set of design principles, is presented in Table 12, with DP standing for Design Principle.

	Context	Intervention	Mechanisms	Outcome
DP1	Markets characterized by nongeneric complements	Increase modularity, by employing 5G technologies such as network slicing, SDN, and edge computing, by means of technical mechanisms such as connectivity platforms, APIs and SDKs, through working together with intermediary parties that create modular interfaces with complementors, and through the use of social mechanisms such as incentives	Making it easier to develop complements stimulates mobility in complementary assets, thereby increasing competition in these assets	A decrease in the value of these complementary assets, relative to the assets where the FF is active, which in turn creates an architectural advantageous position for the FF
DP2	In parts of a market architecture where the FF is active	The FF should restrict mobility by strengthening the appropriability regimes	Through an increase in barriers of entry and a decrease in competition	The value of these assets increases, relative to complementary assets in which the FF is not active, which creates an architectural advantageous position for the FF
DP3	For those components in which the FF is not active, and which do hold strategic value	The FF should focus on weakening the appropriability regime for these components by developing them and making (parts of) them publicly available	Since the public availability of such components will weaken their strategic value	Which will increase the relative strategic value of the components that the FF does hold.
DP4	In attracting developers of complements for a layered modular architecture, especially in the early phase of a market	The FF should aim for complements that require investments that are relatively high in fungibility	As, through a reduction of the fear of being locked in	This would make complementors more eager to participate
DP5	For those complement developers that are already tied into the layered modular architecture	The FF should aim to let these complements be supermodular or unique	As this will make participants more eager to make the combined product succeed	Thereby increasing the potential value of the layered modular architecture and its complements
DP6	In the initial phase of a platform market	The FF should aim to attract interested third-party complementors, build larger networks of interested parties, and build in-house complements	As this creates more innovative activity, reduces uncertainties related to the platform, opens up the opportunities for knowledge spillovers, creates incentives to innovate through competition, and creates incentives to help each other in generating business	Which would then lead to a higher quality and variety of components, and a higher value of the platform
DP7	When following a component strategy, or a bottleneck strategy in a crowded bottleneck	The FF should focus on collaboration, specifically on co-creating value with complementors, and on innovation in both its collaborative aspects and its components	As this will let the FF be able to have access to complementary components, to improve its own services, to differentiate itself from other component competitors, and to reduce investment risk	Which will allow the FF to create and appropriate more value
DP8	In the initial phase of a generative technology in a layered modular architecture	The FF should exert dynamic control, by influencing and monitoring its environment, by employing mechanisms such as roadmapping and showing successful examples, and by updating its strategies	Since through an increased ability to commit resources to the right applications, to gain control over bottlenecks, and to make sure partners also keep committing to the right applications	The FF will be more able to create and appropriate value
DP9	In the phase where actors focus on letting a new market emerge, and where dominant players from different industries are involved	The FF should not attempt to dominate the market architecture but instead focus on developing a market which is beneficial to all dominant players	As this would prevent the vicious cycle of resource allocation deferment from occurring	Thereby giving a market a chance to emerge
DP10	When innovation strongly depend on current sociotechnical systems, and these sociotechnical systems in turn are considered stable	The FF should engage in controllable innovation by focusing firstly on improving existing environments, engaging in combinatorial innovation, and by innovating in controlled environments	Since through decreasing the complexity of innovation	This makes successful innovation more achievable

Table 12: Final set of design principles

5. Discussion and conclusions

This thesis set out to answer a central research question, which was divided into two sub-questions. In this chapter, these questions will be answered according to a summary of this thesis.

5.1 Answering the research questions

The first research question, was how the context of 5G-related business innovations in the Dutch market, could best be characterized. This was firstly done, by characterizing 5G technology as a layered modular architecture. The important implication of this was, that in layered modular architectures, combinatorial innovation is possible, which allows for many potential complementary innovations to be created, on top of that layered modular architecture. This is therefore also, what makes 5G a generative technology.

Due to this modularity as the coordinating mechanism, what in fact is created, are markets consisting of complements. From the perspective of the operator, this can be characterized as multi-sided markets, as different use sides develop complementary services, through the network of an operator. Furthermore, a critical characteristic of such market architectures, is that there always are components which hold more value, strategically, than others. These components are bottlenecks. Furthermore, interactions in these markets are found to be embedded in somewhat stable sociotechnical regimes. For instance, many organizations work with legacy systems, which would need to be altered in order to allow 5G-related innovations to be created.

In this context of layered modular architectures, with multi-sided markets consisting of complementary components, there are some inherent types of uncertainties. As the current market architectures for 5G-related business innovations are only just emerging, the eventual structures, bottleneck components, successful value propositions, and so on, are still very uncertain. In general, this uncertainty is exacerbated in layered modular architectures, due to its generativity. These types of uncertainty also make value appropriation and creation inherently more uncertain.

Finally, there are some typical dynamics which characterize this context. An important one, is that bottlenecks may change over time, as new solutions are discovered, or as actors manipulate the market- and technical architectures. Furthermore, there typically are some feedback dynamics in how complementary actors interact with each other, with for instance increases in momentum leading to increasing clarity.

The main research question, then focused on how operators should strategically act in this context. To answer this question, design principles from both research and practice were derived. From these principles, a number of solution directions can be derived.

First of all, operators should focus on building modularity into its network. This can be done in multiple ways, such as through building certain 5G capabilities (e.g. network slicing) into its network, through developing APIs and SDKs, and through developing connectivity platforms. In creating this technical modularity, the operator enables complements to be more easily developed based on its network, thereby stimulating complementary activity. Within creating this technical modularity, operators should also concern themselves with building some in-house complements in the early phase of the market. As such, operators can showcase to other complementors how complements can be developed (e.g. how SDKs can be used), and what exactly can be developed. Furthermore, it was also found that operators can collaborate with intermediary actors, who specialize in integrating the network of an operator with the complementary services. As such, these intermediary actors are then in fact responsible for creating modularity in the system.

A second solution direction, would be to adjust the appropriability regimes of the market architectures. The relating design principles dealing with this solution direction, were solely based on theory. That is, interviews did not uncover any ways in which operators adjust these regimes. However, after conducting alfa-testing sessions at Strict, two directions were identified. Firstly, operators already engage in strengthening appropriability regimes, by acquiring spectrum through the national spectrum auctions. In many countries, operators are only allowed to deploy a network when they have acquired government-owned spectrum. The costs of acquiring the necessary spectrum bands can be enormous (Rijksoverheid, 2019). Secondly, some ideas were generated on how the telecom industry as a whole, might ensure that the appropriability regimes for assets, that lie outside the telecom industry, are weakened, which would make the position of the telecom industry stronger. When one takes as an example, the automation of airport processes. Then, what would typically be needed, are super connectivity (5G), sensors (IoT), and AI. Now, when one assumes that for most airports the processes are relatively similar, then one might also assume that the underlying AI algorithms share similarities. If the latter is the case, then the telecom sector (e.g. in consortia forms), might focus its attention on creating such AI algorithms themselves, and bringing these then in packages freely on the market, publicly available. If this indeed is a feasible solution, then the strategic value of AI in airport settings would drastically decrease, which increases the relative strategic value of 5G connectivity.

The third solution direction entails attracting partner organizations, and collaborating with complementary providers. Operators should focus on attracting partner organizations, firstly because this can stimulate the amount of complementary activity. Furthermore, building large networks of partners, allows for positive reciprocal effects, as partners can recommend each other to the organizations they are involved with, as such helping each other in stimulating business. Furthermore, collaboration between operators and complementors should evolve to one in which principles of co-creation are adopted. That is, services should be fully based on customer needs, which requires new ways of communicating with customers and therefore complementors. Also, this way of collaborating allows operators to decrease risk in investments, by ensuring that investments will actually be used for intended purposes.

The fourth solution direction argues that operators should focus on innovation settings which are reasonably controllable. What this means is that when engaging in innovation efforts, operators should take into account which dependencies are at play, and how the existing sociotechnical regimes govern these efforts. For instance, when a factory has just recently adopted a connectivity solution based on Wi-Fi, the chances are rather low that the organization owning the factory is willing to change to a 5G solution. The implication of this practice-based design solution, is that operators should focus their attention firstly on connecting with those complementors, who focus on automating existing environments and processes. Furthermore, operators should refrain from those complementors who wish to develop very radical and extensive innovations, requiring many changes to existing systems. Instead, it is advised that operators focus on connecting with those, who aim to engage in combinatorial innovation, by taking use of existing systems, and changing these one step at a time. Closely relating to this, is the research-based design principle which argues that operators should only engage with complementors who develop complements that are relatively highly fungible. That is, investments that are highly specific pose a risk of failure, for the complementor and therefore indirectly for the operator. When failure then does occur, these investments can often not be redeployed. Instead, when investing in less specific complements, investments can, even in the event of failure, often be redeployed more easily, and as such the risk is much lower. This is especially important in the early phase of market emergence, as uncertainty and risk are then already that high.

Finally, the fifth solution direction on how operators should strategically act, argues that operators should exert dynamic control. That is, through influencing, monitoring and updating, operators can deal with the different types of dynamics and uncertainties, that are so present in the initial phase of markets based on nongeneric complements, in layered modular technical architectures. Specifically, empirical research uncovered that popular mechanisms, through which this can be done, are roadmapping and showing successful examples.

5.2 Practical implications

This study has several implications for practice. First of all, it should be noted that currently, the typical telecom operator does not think in the terms which are prescribed by the research-based design principles. Some of these are found in practice nonetheless, but for most design principles from theory, no versions are found in the empirical context. This is telling, since the contextual factors described in theory, were in fact found in the empirical context. The recommendation then for operators, is to change its focus when engaging in 5G-related business innovation. So, rather than focusing on providing coverage and connectivity, in business settings the focus should be on the principles outlined in the provided design principles, for instance on stimulating modularity.

Another practical implication comes from the timing of this thesis. At this moment, we are only at the very beginning of the markets that are emerging around 5G. As such, this is the time when operators really should start thinking about how technical- and market architectures should be shaped. Furthermore, operators should take note of the fact that the context which is described in this thesis, may quickly change once markets are actually taking shape. That is, the ambiguous market interfaces, with high uncertainty and many dynamics, can soon turn into a much more clearly defined environment, when 5G-related business innovations are being successfully brought onto the market. This in turn, is why operators should continuously monitor their environment, especially on the contextual factors described in this thesis.

Finally, the context and design principles outlined in this thesis, can act as a means for operators, and all telecom industry practitioners for that matter, to better understand their environment, and more importantly, why acting in certain ways would achieve beneficial results. It was for instance noted during interviews, that even though operators do engage in certain behaviors that are indeed prescribed by theory, such as stimulating modularity, they did not explain how or why this worked. Then, it can be argued that a more complete understanding of why prescribed principles work, would lead to better results in the competitive environment.

5.3 Theoretical implications

This thesis research has some theoretical implications. Firstly, this research contributes to the strategy literature. That is, through an extensive analysis of the context, a comprehensive body of guiding principles has been derived to inform strategic action. It combines relatively new insights on the types of uncertainty and dynamics that are found in this specific context of layered modular architectures, and nongeneric complements (Dattée et al., 2018; Cennamo, 2018; Jacobides et al., 2018). As the integration of these perspectives was indeed found to be valid, since the context was also found in the empirical data, it appears that such an integration can inform strategy design. As such, this thesis offers a relevant new perspective to the strategy literature.

Furthermore, this thesis also suggests, that the abovementioned perspectives, can be extended by taking explicitly into account how the sociotechnical regime, as defined by Geels (2002), and Geels and Schot (2007), influences the interactions around, and possibilities of, innovation. Specifically, this thesis suggests that also in the case of anticipated generativity, evolutionary adoption processes should be expected, simply because the system is not yet 'ready'. So, rather than expecting large leaps in which we suddenly have fully automated factories, we should expect combinatorial innovation in which new propositions are created one step at a time. This is therefore a perspective that can be adopted in the strategy literature.

5.4 Limitations and future research

Finally, this thesis has a number of limitations, and offers a few directions for future research. First of all, the sample size of participants is relatively small. This is due to time limitations, and due to a few last-minute cancellations. Even though saturation, and overall consensus between the theoretical and empirical context, was reached, this still decreases the reliability of the results. In the same vein, more roles in the market, such as specialized research institutions, or more startups, could have been interviewed.

The second limitation, is that due to time constraints, little testing has been conducted. Since testing is obviously a crucial part in a science-based design approach, this is a lacking factor in this thesis. Though the deliberate choice was made to focus more time on outlining the strategic context, it holds still true that more testing would have gathered valuable feedback, leading for instance to uncovering boundary conditions, which have made the final design more concrete.

Thirdly, this research only provides a snapshot of the current situation. For this reason, empirical dynamics were only based on narrations of interviewees, rather than on observing actual dynamics taking place in the market.

Finally, this thesis only considers on an abstract level what the strategy design for an operator should be. However, this does not consider how operators then should change from the current situation to the future one. Again, this was not done mainly due to time constraints.

This fourth limitation also immediately provides a good avenue for future research. That is, it was already stated by multiple interviewees that operators are not well prepared for the future situation, in which value must be created from 5G-related business innovations. Logically, it would be interesting to research how operators then should transform themselves, from an organization which is organized for mass with a heavy focus on reliability and providing national coverage, to an organization which focuses on concepts such as modularity and complementarity, and engaging in the local co-creation of value.

Another good research direction, would be to conduct this research, over a prolonged period of time, thereby also getting rid of the snapshot limitation. It is to be expected that following operator behavior over time in this context, would uncover much more interesting and clearer dynamics and behavior patterns. As such, this would lead to a better informed strategic design research.

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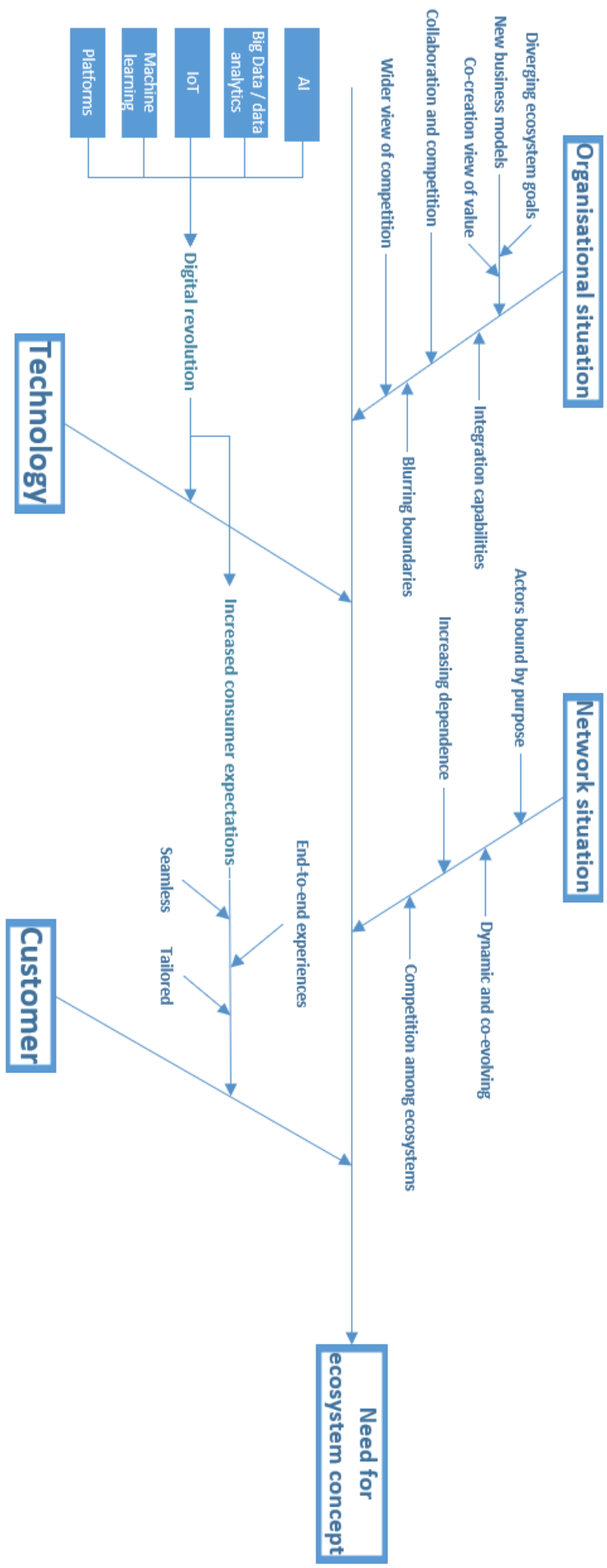
Appendices

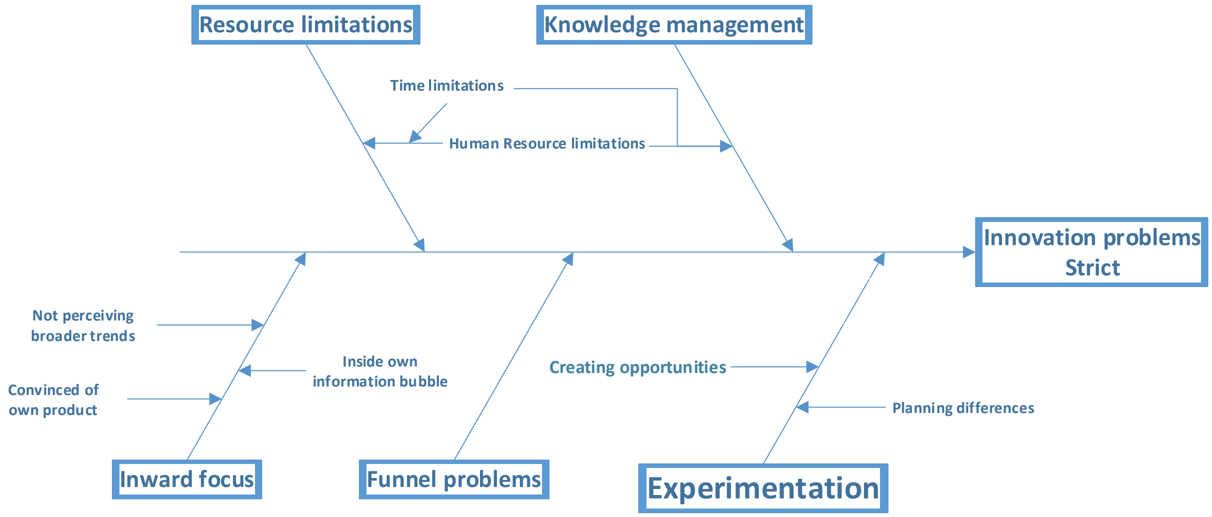
Appendix A – Cause-and-effect diagram of broader market trends



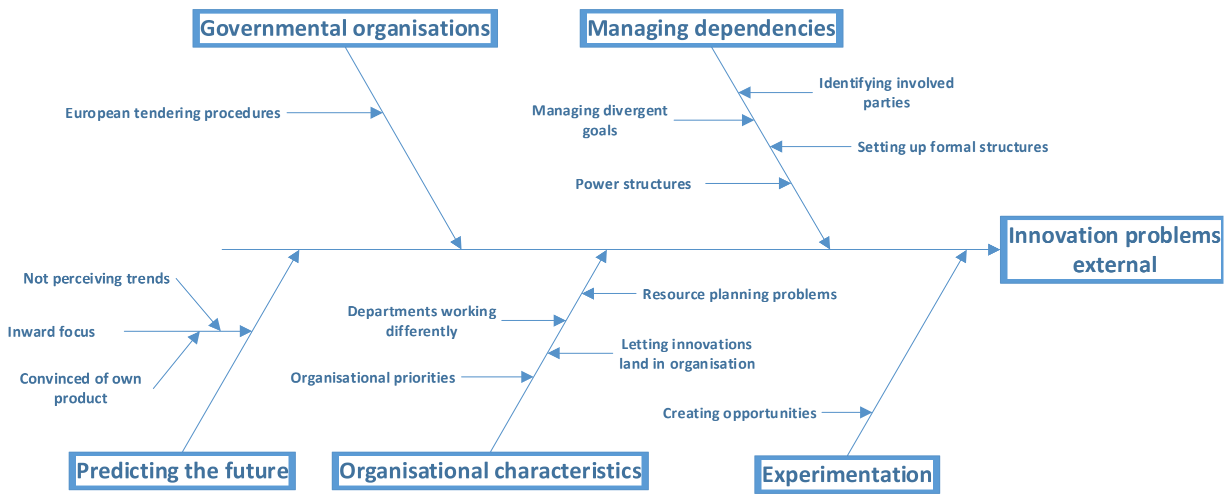
Appendix B – List of interviewees initial interviews

Interviewee	Organization	Function	Duration interview (min)
Interviewee 1	Strict	Principal consultant	47
Interviewee 2	Strict	Innovation and management consultant	50
Interviewee 3	Strict	Junior consultant	33
Interviewee 4	Strict	Sector manager government	39
Interviewee 5	Strict	Consultant	36
Interviewee 6	Strict	Projectmanager	45
Interviewee 7	Client	Team- and account manager	45
Interviewee 8	Client	Management	55
Interviewee 9	Strict	ICT consultant and projectmanager	56

Appendix C – Cause-and-effect diagram of innovation problems Strict



Appendix D – Cause-and-effect diagram of innovation problems client



Appendix E – List of interviewees main interviews

Interviewee	Organization	Function	Duration interview (min)	Date
Interviewee 1	Strict	Principal consultant	47	24-5-2019
Interviewee 10	Startup	Entrepreneur	66	23-7-2019
Interviewee 11	Port authority	Chief Innovation Officer	70	23-7-2019
Interviewee 12	Municipality 1	Program manager connectivity	34	29-7-2019
Interviewee 13	Municipality 2	Program manager economy and tourism	48	30-7-2019
Interviewee 1	Strict	Principal consultant	125	8-8-2019
Interviewee 14	Operator 1	Senior business developer	44	14-8-2019
Interviewee 15	Digital innovation institute	Managing director Benelux	39	22-8-2019
Interviewee 16	Technology vendor	Business development 5G and IoT	52	23-8-2019
Interviewee 17	Municipality 3	Strategy advisor	35	26-9-2019
Interviewee 18	Operator 2	5G product manager	57	26-9-2019
Interviewee 19	Operator 1	Technical lead 5G lab	55	22-10-2019
Interviewee 20	Operator 3	Sales director B2B	62	5-11-2019
Interviewee 21	Operator 3	Technology strategist	62	5-11-2019

Appendix F – Interview guide

For the main interviews, open- and semi-structured interviews were used. That is, interviews were semi-structured in the sense that topics were identified, which led to the construction of a set of predetermined open-ended questions, with most subsequent questions being based on these topics (DiCicco-Bloom and Crabtree, 2006). At the same time, parts of the interviews had an open nature, as it was deemed important to let interviewees talk about what they thought most important in the context of 5G. The topics and questions were defined before the first interview, being based on the initial empirical research, and findings from the main-phase literature research. Based on advanced understandings of the context, the protocol has been adapted throughout this thesis research. Furthermore, the protocol was adapted based on the interviewee. That is, some interviewees had specific knowledge on the technology, the business side, the municipality, and so on. In this appendix, all the questions that have developed are provided below.

Furthermore, some techniques guided these interviews, mostly based on principles from Eisenhardt (1989). For instance, when talking about processes, I often aimed to let interviewees provide their stories through event-tracking, in which a story is told in a chronological order of events. Furthermore, questions were nondirective, interviewees were asked to be specific or to elaborate/explain when answers were deemed vague, or when answers or concepts were not understood.

Set of questions:

1. The research will be introduced. I will describe to the interviewee that this research aims to uncover how 5G-related business innovations are developed, and which role the operator should play in that. Furthermore, I will describe how this research aims to uncover how the context of 5G-related business can be characterized. That is, which organizations are the most important ones, what are their goals, which uncertainties and risks do they see, and so on.

2. Background:
    - First, I will ask the interviewee to introduce him/herself.

3. Markets of 5G – general:
    - How does your organization see 5G currently
        - How has the company's view of 5G been developing over the past years?
    - What is the goal of your organization regarding 5G?
    - How would you describe your organization's strategy regarding 5G?
        - Does this differ per type of application?
        - (For an operator): for instance, I can imagine that there might be applications for which it will mostly about deploying a national network, but there will also be applications for which you need to create specialized solutions. Does this influence your strategy?
    - What do you see as the most important benefits of 5G?
    - What do you see as the most important problems relating 5G?
        - For instance, are there factors which form an obstacle for the deployment of 5G networks and for the delivery of 5G services?
            - In terms of legislation, the attitude of involved parties, organizational-wise?
    - Which applications do you see as most important for the next few years?
        - Or, if not applications, which developments?
    - Which developments do you currently see happening around 5G?
    - Do you have an idea about how 5G strategically relates to other technologies such as Artificial Intelligence (AI) and Internet of Things (IoT), and how this might differ per application group?
        - For instance, when developing applications to automize a factory, which technologies are crucial, pose the biggest challenge, can easily be replaced by a competitor offering the same technology, and so on?
            - Note to interviewer: example application can be changed based on the context of the interviewee. Thus, factories, ports, autonomous vehicles, and so on, can all be used to clarify what is meant here.

4. Markets – specific cases the company has been involved with:
    a. Can you describe some of the specific cases with which your organization is currently involved?
        i. How do these cases come into existence and can you describe the process through which they are developed?
            1. How did the involved organizations come together, and does this differ per case?
            2. What were the most important events in developing the actual innovation?
        ii. Which parties play a role in these cases, and what are their roles?
            1. How were these roles, the division of labor, established during the process?
                a. How did these talks go? Was it easy to establish who does what? Or is it a process of searching for the right division?
                b. How does this evolve during the process? Are all parties there at the start, or does it grow?
                c. What is your role as an operator, what is the nature of the service that you deliver?
        iii. How is value appropriation defined?
            1. If it is defined, could you describe the process, or the negotiations, through which it was defined?
        iv. What are the goals of the involved parties?
            1. Were there any conflicting goals, and if so, how did the talks about these conflicting goals go?
            2. How was decided who gets what out of it? In terms of financial value, knowledge, societal value? How did these negotiations go?
            3. How do operators approach this innovation?
                a. What is their specific interest?
        v. Are there any typical problems which you encountered during these cases?
            1. Or, which components/parties are subject to the biggest challenges?
            2. For example: technical problems, problems due to unexpected events, depending too much on others, and so on.
            3. How do the involved parties deal with these problems?
        vi. Have you encountered any kinds of risks or uncertainties during these projects?
            1. Could you describe these, or the most important ones?
            2. For example: uncertainty of what can be delivered technically, uncertainty of which applications are the most promising ones, uncertainty about what partners will do, and so on.
            3. How did/do organizations deal with these risks and uncertainties?

5. Technical structures:
    a. Could you tell me something about the underlying technical architecture of 5G?
        i. What are the most important functional components of a 5G architecture?

ii. How are other complementarities made based on that architecture?
    1. So, based on a 5G network architecture, how exactly would one go about developing complementary services?
iii. What is the role of the operator in this 5G architecture?
iv. Where lie the technological difficulties for operators in deploying a 5G network, and in creating/delivering 5G-based applications?
    1. For instance, network integration (used for specialized services) is currently very complex. Will this become easier with 5G?
    2. Are there things that should change within the organization of an operator in order to overcome these challenges?
        a. What are they?

b. What does the technological structure of the applications you're involved with look like?
    i. For instance a solution for an autonomous vehicle, automated factories or harbors, and so on.
    ii. Can you sketch that structure, with its most important components (in technical and functional terms).
        1. In this structure, what exactly is it that the operator delivers, and what is the advantage of that?
        2. In which of these components lie the biggest challenges from a technical perspective?
            a. Or are there difficulties in combining the different technologies for a particular value proposition?
        3. For which components are there alternatives readily available?
            a. Due to competition or simply other types of technologies that offer the same functionality.
    iii. How does 5G relate to other technologies such as AI and IoT for these cases? Does this differ per case?
        1. For example, to what kind of platform will I connect if I'm developing an application: a connectivity-platform (a 5G network), an IoT-platform, AI-platform?
        2. And who will own that?
            a. For example, companies such as Nokia are developing connectivity platforms where all sensor data in let's say a harbor is combined, and on the basis of which then the involved parties in a harbor can develop applications.
            b. Do you see any developments like these?
            c. What will the role of an operator be?

6. Strategic role of the operator:
    a. How would you describe the strategic advantage that an operator has for developing/delivering the types of value propositions we discussed?
        i. How does this relate to that which other parties (for instance telecom technology vendors such as Nokia, Ericsson, Huawei) can deliver?

b. How do you think should an operator in general behave in this environment?
    i. For instance: should operators collaborate with partners and how should they do that, with whom and how should operators compete, which strategic position should an operator take, should an operator develop applications, and which types of applications should an operator focus, and so on.
c. Do you think the current operators are suited to act in this new environment?
d. How should operators change then?

7. Closing questions:
    a. Did we discuss everything, or are there any matters left which you deem important, which we did not yet discuss?
    b. Can I reach out to you for a second interview, or for any additional questions, in the coming months?

Appendix G – Graphical representation data