Viability of a service-oriented approach on Dutch infrastructure projects

MSc Construction Management & Engineering
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PREFACE

Dear reader,

This thesis includes both elements from my bachelor studies (Civil Engineering), my interest for a more sustainable and circular economy as well as procurement and project-based considerations from my master Construction Management & Engineering. The study has taken many turns along the way, starting with a case-study approach on international projects, just to be faced with the reality of how projects often do not go as planned and I had to rethink my approach.

Finally, I decided to research whether Product-as-a-Service could be viable from a public client's perspective here in the Netherlands and the research became more exploratory in nature. With a technical background I found it difficult at times to make statements based on interviews as they are always affected by the participant's bias. However, I learned through a deep dive into different methodologies how this type of research can give useful insights for the industry, as it highlights the different aspects that need to be taken into account when deciding on how to procure a project.

A graduation project can be very lonely at times, being busy with your own project day after day, but especially during a time of social distancing. The effects of the corona-pandemic became very present in this study as I had to complete all interviews digitally and the bulk of the thesis remotely on an island in the beautiful Finnish Archipelago. I was very lucky to be a member of a supportive group within Witteveen+Bos, as we kept in touch daily. My company supervisor was very supportive with the research, but also making sure that I was coping fine with not being able to use the office and see other graduate students. I was also lucky to be able to join my company supervisor on a few projects before all offices were closed. This gave me a good insight into what the infrastructure sector in the Netherlands looks like, and through my thesis I got to learn even more about public infrastructure in the Netherlands.

I would also like to thank my committee for the time and effort they have put into supporting me and looking over my report and methodology to take the thesis to a next level, especially during times when the direction of the research was not so obvious because of the explorative nature. I do have a deep appreciation for scientists that do research on problem, where the problem is far from obvious.

The study would also not have been possible without the time and expertise offered by the numerous participants I had the pleasure of interviewing throughout my thesis, getting to know much more about moveable bridge, pumping stations and solar energy projects.

Finally, a big thanks to my family with whom I got to spend more time than I had ever imagined during my thesis writing time in Finland. They made sure I got enough to eat and sleep as I was typing away at our summer cottage.

I hope you enjoy reading it!

EXECUTIVE SUMMARY

Introduction

The Netherlands has an infrastructure that scores very high in terms of quality, on a worldwide comparison. However, many objects will reach the end of their intended service life in the coming decades. There is not enough means to pay for a replacement of all the infrastructure that has to be decommissioned (de Witt Wijnen, 2016; Talsma et al., 2018; Arnoldussen et al., 2017; Rijkswaterstaat, 2019) .

Public authorities have also committed to completely circular economy by 2050, including the infrastructure (Rijkswaterstaat circular in 2030) (Dijksma & Kamp, 2016; Rijksdienst voor Ondernemend Nederland, 2018; Rood & Kishna, 2019; Nelissen et al., 2018). New business models are thought to be part of the solution for a circular economy. Huizing (2019) found a service-oriented approach (sometimes mentioned as Infrastructure-As-A-Service) to incentivize contractors to keep the value of infrastructure on a high level if they also own infrastructure. This research develops an assessment framework to assess the viability of such an approach from the point of view of a public client as opposed to a contractor.

Literature review

The literature research focuses on the advances in servicizing since 1977, when Stahel presented the need for slowing down and reducing material cycles. It then progressed in the types of applications, but the same principles of material reduction remain. Because much of the literature is focused on the consumer- and business-to-business market, the transformation of the concepts was done using literature by Markard (2011). Markard presented seven key characteristics of infrastructure that have to be taken into account when transferring concepts to the infrastructure sector, they form the starting point for assessing the viability of a service-oriented approach. The characteristics are:

1 Capital intensity
2 Asset durability
3 Negative environmental impact
4 Regulation intensity
5 Public organizations
6 Competition intensity
7 Systemness

Methodology

A mixed methods design-based research is conducted in order to answer to the research question. The research will collect qualitative data through literature research and semi-structured interviews of experts in three distinct types of infrastructure assets: moveable bridges, pumping stations and photovoltaic systems.

The double diamond design approach is taken as a methodology framework for the research (Fig. 1). The double diamond is split into four parts, discover, define, develop and deliver. For the discover and define part, semi-structured interviews with experts were undertaken in order to gain knowledge on the specific characteristics of infrastructure and how what consequences that could have for a service-oriented approach.

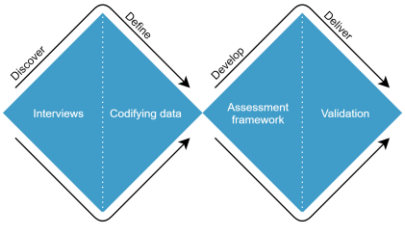

Figure 1 Double Diamond approach

A total of eight interviews are conducted for the discover phase, out of which one had knowledge on both moveable bridges and photovoltaic systems. This gives sufficient triangulation and reduced the influence of personal bias. Overall, the opinions of the experts all point to the same direction (saturation).

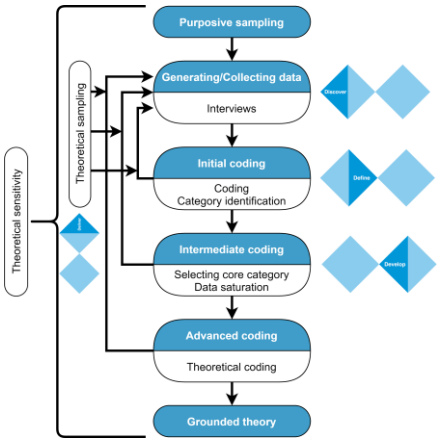

Figure 2 Codifying interviews according to grounded theory

Results

The interviews make it clear that the key characteristics of infrastructure (Markard, 2011) provide a good starting point, however, the different aspects of the public clients and especially the statutory duties play a significant role for the viability of a service-oriented approach. The interviews are codified according to the methodology of grounded theory (Fig. 2). Recurring or emphasized themes are coded and then categorized under six distinct categories:

1 Innovation
2 Integrality
3 Public accountability & ownership
4 Supply
5 Circularity
6 Duration

Clients have standard functional requirements (RAMS) that they apply to projects. These requirements are also applied to the assessment framework. The asset or project in question is first assessed on certain pre-requisite criteria, which here are found to be budget available for both D&C and M&O, together with a life-cycle approach to assets. The client also needs to be able and willing to set functional requirement and have experience and knowledge with performance-based contracting, which is highlighted during validation.

The second step is to set the main functional criteria using RAMS. Once this is done, the asset can be assessed based on the supporting criteria: Innovation, integrality, public accountability & ownership, supply, circularity and duration (of the contract). Once these steps have been complete, a rough financial estimation is done after which an overall judgement is and a decision on whether or not to proceed to the design phase (Fig. 3). Up until now, clients have been apprehensive about such an approach.

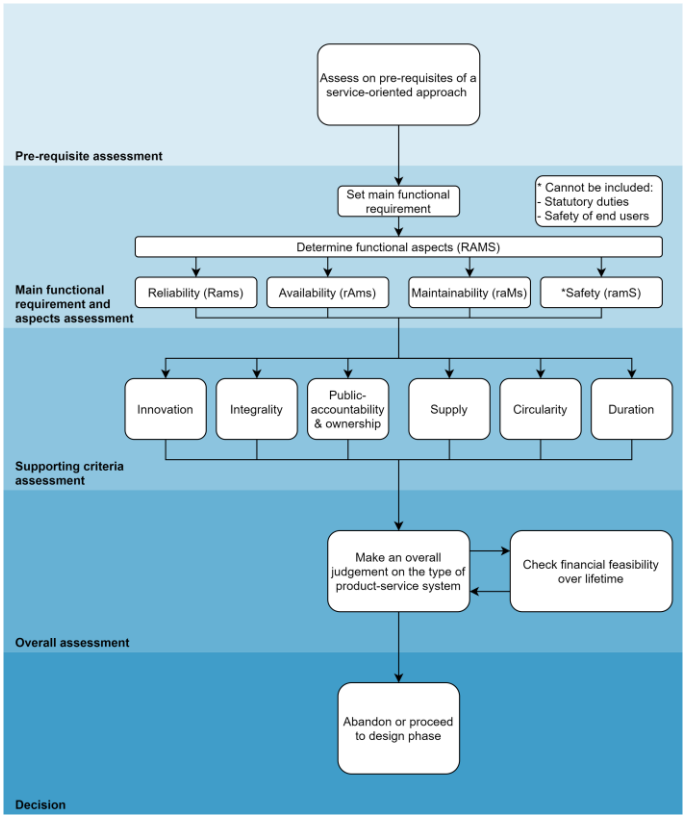

Figure 3 The assessment framework

Discussion & Conclusion

The characteristics of the three infrastructure asset types do not inherently contain characteristics that make them suitable for a service-oriented approach. Rather than finding characteristics that point to the feasibility of a service-oriented approach in the type of infrastructure assets that are researched, the concluding theme is that statutory duties of clients make them very apprehensive to transfer ownership in order to optimize the service life of an asset. However, many of the elements of a service oriented approach, such as functional specifications and total cost of ownership calculations are already widely used by public clients.

The assessment framework gives a pathway to make a judgement on the feasibility of a service-oriented approach. However, public clients are proceeding very cautiously with this type of procurement and the sector will face a shortage of knowledge by the time it should have become fully circular in 2030. Claims in literature (Huizing, 2019), that a service-oriented approach will lead to a circular economy is not supported by the findings of this study. The responsibilities of pubic clients are much broader than the needs of a circular economy and the role of the public client as owner and manager of critical public infrastructure is essential to the Netherlands according to the participants of this study. The theory on a service-oriented approach has to offer options where the ownership is not transferred but the knowledge of private suppliers could be better utilized.

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INTRODUCTION

The Dutch civil infrastructure consisting of 40 000 – 100 000 objects is in very good shape from a worldwide perspective, but many of the structures are built in the '60s and '70s and they are reaching the end of their intended service life (de Witt Wijnen, 2016; Talsma et al., 2018). The total need for maintenance, replacement, and renovation will increase in the coming decade (Figure 1) (Arnoldussen et al., 2017; Rijkswaterstaat, 2019); however, the Dutch government does not have the means to pay for a replacement of all the infrastructure that has to be decommissioned. Simultaneously, infrastructure is being more heavily used than ever before and it needs to deliver more value to the users than before. The infrastructure has to improve on functionality; be better suited for a changing climate; lower in energy use, and the design needs to be circular. Infrastructure projects in the Netherlands are also becoming increasingly complex and they need to deliver more value for a lower budget; they need to be technologically modern and sustainable and fit into the existing infrastructure network to meet the above-mentioned challenges (Koenen, 2019b).

The Dutch State, regional and local authorities have also set ambitious goals on a completely circular economy by 2050 (Dijksma & Kamp, 2016; Rijksdienst voor Ondernemend Nederland, 2018; Rood & Kishna, 2019). The infrastructure sector is on a national level included in this ambition through the 'Transitieagenda Bouw', which sets out steps to be taken both in the short- and long term to reach a circular economy (Nelissen et al., 2018). Provinces and municipalities have also set up their programs to map out the road to a circular economy (de Bruijn et al., 2019). For the period 2018-2021, the infrastructure-wide transition team is mapping out the opportunities, possibilities, and filling gaps in the knowledge to have a good basis when moving to the execution step. As part of the effort to learn from circular buildings projects, Rijkswaterstaat (RWS), the executive authority of the Dutch Ministry of Infrastructure and Water Management worked on a circular viaduct pilot project. Technically, the project was feasible but it is lacking a concrete business model (Chahboun et al., 2019). Viaduct-as-a-service was proposed as a model to finance the viaduct; a consortium would own the asset and RWS would only pay for the use of it (Koenen, 2019a). This would be a continuum of the decision in 2008 that RWS become an asset manager. Another example of a service-oriented approach from the infrastructure sector is a pilot project Road-as-a-Service by Dutch contractor Dura Vermeer. Huizing (2019) described how such a service-model could be applied to infrastructure projects and how to incentivize a contractor to improve on circularity. However, many challenges remain as the infrastructure sector is in many ways different from the consumer market, where the service-oriented approach has its roots.

The infrastructure sector is characterized by a large influence of government, which often has other incentives than purely economic (Markard, 2011). RWS took its first steps towards asset management in 2008 due to changes in its landscape politically and managerially. It became an executive agency, meaning it should from then on only execute tasks given by the government; the infrastructure should serve the public, and RWS should become publicly oriented and a shift from government to private parties to reduce the number of employees on the government payroll. From then on RWS is always tendering projects out to private parties if it is by any means possible ('Markt, tenzij…') (van der Velde & Hooimeijer, 2010). For contractors, this switch has not been a gold mine and their profits are under pressure, risks are high, and innovation is very slow, in comparison to other sectors. RWS aims to reduce short term pressure on contractors and to offer them more long-term incentives, through portfolio contracts, to spin innovations needed in the coming decades (Rijkswaterstaat, 2019). The type of infrastructure discussed here is the ones of public utility (in the Netherlands is called Grond-, Weg, and Waterbouw) varying from national highways to municipal sewers, excluding buildings, such as hospitals and schools.

As an Asset Manager, RWS wants to know what assets it has, what the status of maintenance is, and how this relates to performance as well as what risks can be expected in the future and what it is all going to cost. As part of asset management, RWS has divided the scale of infrastructure into 6 different levels:

7 A complete network
8 A branch of a network
9 A link in a network
10 A main infrastructure object
11 The main parts of an infrastructure object
12 All individual parts of an object

This division can be used to determine to which category an asset belongs to, as the level has a major influence on the perspective of clients. On a network scale, it would more strategic than on a part of an infrastructure object, where it could be either functional or technical.
Infrastructure projects

Simultaneously with changes affecting public clients of infrastructure, infrastructure projects in the Netherlands are becoming increasingly complex and the total need for maintenance, replacement, and renovation will increase in the coming years, see Fig 1 (Arnoldussen et al., 2017; Rijkswaterstaat, 2019). More is expected from these projects; they need to be technologically modern, sustainable, and fit into the existing infrastructure network (Koenen, 2019b). Contractors' profits are under pressure, risks are high, and innovation is very slow, in comparison to other sectors. RWS aims to reduce short term pressure on contractors and to offer them more long-term incentives, through portfolio contracts, to spin innovations needed in the coming decades (Rijkswaterstaat, 2019). The type of infrastructure discussed here is the ones of public utility (in the Netherlands is called Grond-, Weg, and Waterbouw) varying from national highways to municipal sewers, excluding buildings, such as hospitals and schools.

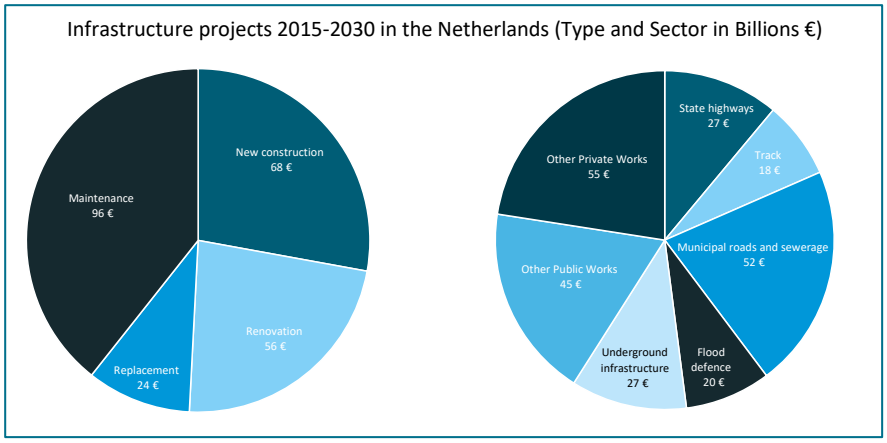

Figure 1 Planned infrastructure projects in the Netherlands (Billions €)

The infrastructure sector is often considered conservative and it has a very low share, 0.02 per mille of research and development, as a share of the total output of the sector in the Netherlands. Even capital- and labor-intensive sectors on average have a much higher share of research and development (36 and 17 per mille respectively). Multiple reasons are given for this low level of innovative behavior, most importantly, the lack of necessity to innovate, which is in a large degree due to the project-centered approach, which does not encourage sharing knowledge, and the task as a contractor to deliver projects within a previously determined framework (De Bruijn et al., 2005).

The infrastructure sector in the Netherlands works with a set of standard contracts of which DBFM gives the most freedom, and responsibility, to the contractor to realize a project and its functional specification. This type of contract however only covered 12% of the total revenue in the sector in 2018, with traditional RAW-contracts written on technical specifications is used the most (37%) (Fig 2) (Visser & Nicolas, 2020). All types of construction contracts and project delivery models (PDM) have their specific use and it is not feasible or even desirable to have all projects or public infrastructure needs delivered through a service-oriented approach. DBFM contracts were also initially positively received in the Netherlands, but after serious setbacks in multiple projects, RWS has found it difficult to get new DBFM projects started due to a lack of interest by market parties. It is however the type of contract (from the currently existing ones) that resembles a service-oriented approach the most. It is then of utmost importance to be able to recognize in what kind of situations such an approach is promising, to avoid upsetting clients and contractors through setbacks that sour the enthusiasm for circular approaches.

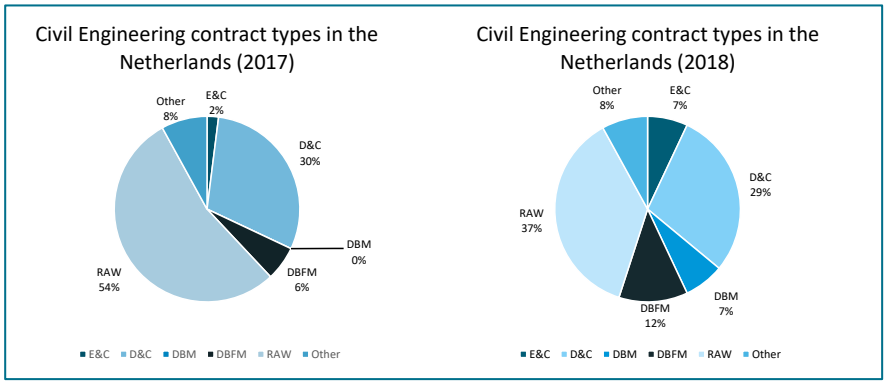

Figure 2 Distribution of Civil contracts in the Netherlands

All the above-mentioned topics, circularity, asset management approach and infrastructure contracts are tools to meet certain goals. Even the circular economy can be seen as a tool to live more sustainably, be more self-sufficient on materials, and retain value in infrastructure (Dijksma & Kamp, 2016). The circular economy is thus no independent goal. A service-oriented approach is a type of project delivery model, which is thought to aid the transition towards a circular economy and the higher-order goals.

1.1 Problem definition

As public infrastructure projects in the Netherlands become more complex and the need for them to solve a wide range of problems grows, clients (public authorities) have started to increasingly set functional requirements rather than technical requirements to allow for contractors to come up with creative and innovative solutions that are economically advantageous and come at a lower environmental cost and deliver more value for the client. To guarantee providers of infrastructure a continued revenue stream in an economy where the demand for completely new infrastructure is decreasing and material loops are closed, infrastructure could be provided through a service-oriented approach. However, infrastructure projects are often complex, and the infrastructure sector is inherently different from many other sectors where a service-oriented approach has become widely accepted. A service-oriented approach is not suitable or possible for all infrastructure projects or all stages of a project. Theories on servicizing and Product-Service Systems do not extend to a wider application in Dutch infrastructure projects and there is a clear gap in both scientific literature and practice on when a service-oriented approach might be successful for Dutch infrastructure projects.

1.2 Thesis objective

This thesis aims to present an assessment framework on the viability of a service-oriented approach in Dutch civil infrastructure projects, to be used at the exploration phase of a project evaluated by governmental, provincial or local public clients.

To build such a framework, the characteristics of a service-oriented approach are gathered from scientific literature and translated for use in the infrastructure projects, taking into account the specific characteristics of the infrastructure sector. Interviews will initially be conducted to see how the information necessary to use the assessment framework can be gathered in the initial phase of a project and thereafter to validate the framework by making sure it is useful for making an assessment.

1.3 Research question

Based on the above-mentioned problem and objective, the following research question is presented: "Under what conditions is a service-oriented approach viable for Dutch infrastructure assets of public clients?". This question is further divided into four sub-questions concerning literature research, the methodology, results, and discussion.

1.4 Sub questions

1. What are the characteristics of a viable service-oriented approach of an infrastructure asset?
2. How to assess the viability of a service-oriented approach of an infrastructure asset?
3. In what way does the assessment give insights into a service-oriented approach of a planned infrastructure asset?
4. What are the implications of a service-oriented approach for Dutch infrastructure assets, currently managed by pubic organizations?

1.5 Outline

The research begins by presenting the current state-of-the-art literature of servicizing in the infrastructure sector. Circularity, functional economy, product-service systems, and key characteristics of infrastructure are discussed in chapter 2. Chapter 3 presents the methodology and goes through the double diamond design method. Chapter 4 presents the results of interviews with experts of three distinct types of infrastructure. Chapter 5 is the discussion on the findings and how they correlate with the scientific literature. The last chapter, chapter 6, concludes the findings, answers the research question, and provides an outlook on how the service-oriented approach can be used to provide a solution for the problem presented here above.

2

LITERATURE REVIEW

2.1 Introduction

This chapter presents the progress on literature around the need for a reduced environmental impact, a more service-oriented approach, and what specific characteristics of the infrastructure sector influence the use of such concepts as product-service systems for infrastructure purposes.

2.2 Circularity

The idea that the production of goods cannot continue to grow at the same pace as economic growth, is not a new one. As early as 1977, Stahel & Reday present a model for replacing industrial production of products using virgin materials, with reconditioning of products by using an increased labor force. The most far-reaching solution presented in the report is a *systemic* one. A systemic solution according to Stahel & Reday (1977) is a combination of reducing the volume and speed of resource flow (less material is used and it ends up at a landfill at a slower pace) together with closing liability loops (the producer/supplier remains responsible for the recycling of materials). This is especially true for industrialized economies that have sufficient resources and infrastructure. The infrastructure related budget in these economies is increasingly for operation, maintenance, and renovation and less for new construction. This is also true for the Netherlands, where Rijkswaterstaat mentions that the challenge is first and foremost the renovation or replacement of existing infrastructure that is reaching its end-of-life stage in the coming decade (Rijkswaterstaat, 2019; Spiering et al., 2010). To slow the resource flows, the manufacturing sector should according to Stahel & Reday (1977) agree on "global standardized components" and "regional remanufacturing" (p. 99) to decrease the use of virgin materials. This idea is one of the centerpieces of circular realization in the infrastructure sector.

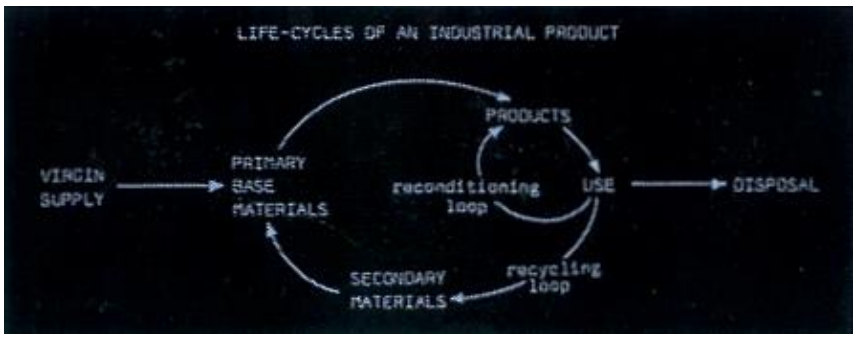

Figure 3 Life-cycles of an industrial product (Stahel & Reday., 1977)

Building on the ideas from a decade later, Börlin & Stahel (1987) presented four steps: manufacturing long-life products, increasing the life of already produced products, increasing the life of sub-components and remarketing used products for new purposes, to reduce the use of virgin materials and to close material loop. To close the liability loops they recommend increasing manufacturers' product responsibility by introducing the cradle-to-cradle concept (Figure 3). Further concepts introduced were selling 'use' – instead of goods, shared services, services replacing the sale of goods, results instead of products. Bring-back guarantee with a financial incentive was also introduced. Building on the ideas of product responsibility, the functional economy, meaning an economy where the "use" of products is central, was thought of as a solution as manufacturers would have the incentive to realize the above-mentioned goals of reduced material use.

2.3 Performance economy and servicizing

A functional economy was defined (1997, p. 91) by Stahel as "one that optimizes the use of goods and services and thus the management of existing wealth", to "create the highest possible use-value for the longest possible time while consuming as few material resources and energy as possible". In this paper, the term "servicizing" was also introduced. The economic incentive of such an economy according to Stahel is to make use of the products that have already been produced. Servizicing (or servitization as it is also called) has been popularized as a foundation for inherently sustainable business models.

2.4 Circular business models

To meet the circular economy goals set by the Dutch Government and regional and local authorities (Dijksma & Kamp, 2016; Rijksdienst voor Ondernemend Nederland, 2018; Rood & Kishna, 2019), Van Boesschoten (2017) argues that the Product-as-a-service (PaaS) model offers a new revenue model for businesses that detaches the economic profit from the use of natural resources. According to Boesschoten (2017), the use of PaaS enables five things:

1. Saving natural resources by switching ownership from the consumer to the producer;
2. Matching the needs of consumers by supplying experiences rather than ownership;
3. Price discrimination by using new technologies such as Internet of Things (IoT);
4. Improved consumer relation through continuous and direct personalization of PaaS;
5. Increased profitability by increasing the value to the consumer and simultaneously saving on costs and realizing a revenue model based on periodical payments.

The model has been aimed at the consumer market and the examples that are given, often relate to transportation, such as Mobility-as-a-service and an example thereof would be the offering of cars by-the-minute in Amsterdam by ShareNow (ShareNow, 2020). Software and entertainment are also more and more offered via the PaaS model. For business-to-business applications, examples include Printing-as-a-service, Light-as-a-service, and Accounting-as-a-service. Rijkswaterstaat also thought of introducing a viaduct-as-a-service model for its circular viaduct project (Chahboun et al., 2019).

Although the service-oriented business models are introduced in the discussion of circularity they are by no means new ideas, as they have been around for several decades. The PaaS model has been mentioned in literature as a subcategory to Product-Service Systems, which is presented below.

2.5 Product-Service Systems

Goedkoop, van Halen, te Riele & Rommens (1999), introduced the ideas and concepts presented above under a new name Product-Service Systems (PSS). PSS was defined as a *"marketable set of products and services, jointly capable of fulfilling a client's need"* (p.18), with the goal of *"unlinking economic growth from ecological impact"* (p.18).

The motivation the authors gave for their work, was that while industries had efficiently made their processes cleaner, reduced emissions and increased recycling, the overall consumption of products had continued to increase, at least in part due to the rebound effect, whereby efficiency improvements lead to increased consumption rather than a lower use of resources. They wanted to find a way to unlink economic growth from the consumption of products. They proposed to consider using PSS when it created more financial value for a given environmental load. The systems considered in the paper were business-to-consumers (B2C) cases such as car-sharing and mobile phone services and business-to-business (B2B) cases such as professional launderettes and coffee systems.

Goedkoop et al. (1999) presented three criteria on which the organization supplying PSS should be checked in the strategy analysis:

1. Is the structure and level of decision making of the organization or business appropriate for PSS?
2. Do the employee skills, knowledge and attitude match the demands of PSS?
3. Is the innovation routine of the organization or business capable of renewing and improving products and services?

Once it has been determined whether an organization is appropriate for supplying PSS, the PSS would be compared with the reference system based on purchasing a product.

A four-step process for comparing a PSS to the status quo reference system (Goedkoop et al., 1999):

1. Rank the most important features of both systems
2. Score both the PSS and the reference system according to the ranking
3. If the PSS scores well on the second step, check whether the communication and marketing strategy is strong
4. Based on the three steps, determine the relative strength of the PSS in comparison to the reference system.

For the introduction of PSS into markets where it has previously not existed, the authors mentioned the MAYA principle (Most Advanced, Yet Acceptable) to be the most applied method of introducing new PSSs. MAYA is a principle thought of by industrial designer Raymond Loewy and means that a radical idea is not introduced at once, but rather the most advanced version of a generally accepted idea, which is then continuously updated to eventually reach a solution that initially seemed very radical and unacceptable by a majority of people (Thompson, 2017).

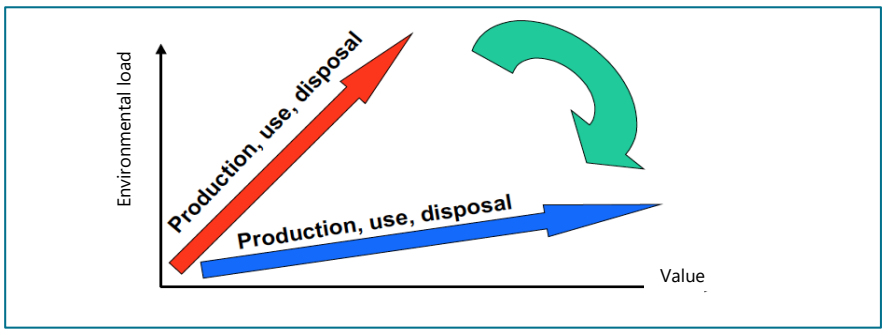

Figure 4 E2 Vector (Goedkoop et al., 1999)

The authors also presented the E2 vector (Figure 4) as a method to evaluate the PSS to the reference system from a value/environmental impact perspective. The E2 vector shows the environmental load versus the cumulative value creation over the lifecycle of the system. If the steepness of the vector of the PSS is lower than that of the reference system, overall it can provide for a lower environmental footprint for the same value, or more value with the same environmental impact. The variables would have to be translated into monetary terms to be comparable with each other. The value of a PSS can be estimated through market forces, while the environmental impact of a PSS over the complete life-cycle is more challenging. The authors recommended using a life-cycle analysis (LCA) to determine the environmental impact in monetary terms. In an LCA, the depletion of resources and harmful emissions are given a monetary value to determine the environmental impact in monetary terms. To date, LCA continues to be the industry standard for measuring environmental load, even though it does not take into account the reuse of products or materials (Goedkoop et al., 1999). At the onset, it is also difficult to determine what the impact of the use-phase will be, which is an essential part of a PSS.

Mont (2002) stated that the "paramount goal of PSSs should be to minimize the environmental impact of consumption" (p. 240). The reduction in the environmental load should be achieved through closing material loops; a reduction in consumption; increasing the productivity of resources and providing systemic solutions (e.g. (Stahel & Reday, 1977)). In the early scientific literature on PSS, a reduction in the environmental impact of producing goods was a central aim. In (2004), Tukker presented the idea of looking at the overall value of PSS, rather than purely the environmental impact.

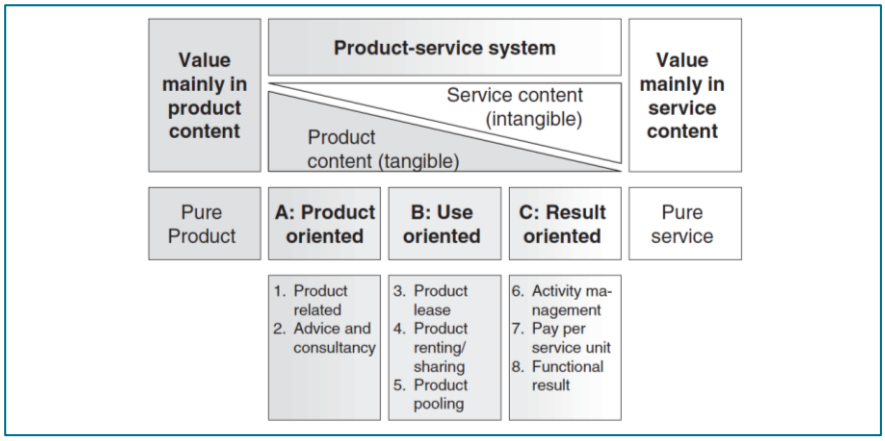

Figure 5 PSS classification (Tukker, 2004)

Tukker (2004) identified that there are varying degrees of servicizing within PSSs that depend on the service content versus product content. The author classified the systems into three main categories based on previous published scientific literature (
Figure 5). The categories were product-oriented, use-oriented, and result-oriented. In theory, the result-oriented has the biggest potential for creating value and reducing the environmental load but simultaneously it also results in a much bigger liability risk for the provider if the agreed results are not achieved. The author found that all types of PSS were no worse off environmentally than the reference system unless uncareful behavior was possible, such as when leasing products to consumers. However, improvements in the form of higher economic value lower environmental impact compared to the reference system were mediocre at best and were mainly economic.

Tukker (2004) listed four elements to answer the question "which factors determine whether a PSS business model is the best way to create value added?" (p. 249):

- The market value of the PSS (tangible and intangible);
- Production costs of the PSS (including risk premium aspects);
- Investment needs/capital needs for PSS production;
- The ability to capture the value present in the value chain, now and in the future.

The market value of a PSS according to Tukker (2004) is split into tangible value provided by the PSS in form of resources, time input, and saved capital costs as well as intangible elements without a monetary value. The production costs are split into the traditional production costs as well as a risk premium due to the uncertainty related to the solution. The investment needs consist both of the production of the solution as well as additional expenditures to either transform into a PSS or build it from scratch.
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Ability to capture value relates to the position of the PSS in the value network, e.g. how big a portion of the total revenue of a network is produced by the PSS, how important is it for the functioning of the overall network and whether it is serving the end-user of if it providing a solution for an intermediate step. Additionally, barriers of access should be low and customer loyalty high to achieve a high value-added according to Tukker (2004). The speed of innovation should also be higher than that of the reference system to achieve a higher value-added. For a pay-per-unit business model "A very important issue is that the provider feels an incentive to continually improve the product with life-cycle performance in mind" (p.257).

Tukker & Tischner (2006), clarified further that PSS does not automatically result in win-win situations from both the economic or the environmental point of view. According to them, innovations often start as a niche within a "protected space" (Tukker & Tischner, 2006, p. 1554) and more often than not, never reach the mainstream market. The barriers to change for PSS were identified to be the socio-technical regime (financiers, users, suppliers, and authorities) and the landscape (infrastructure, values, and dominant paradigms). Infrastructure is thus seen as one of the barriers to the broader application of PSS in the scientific literature.

In (2015) Tukker summarized that since 2006 more attention had been given to organizational questions within the PSS community and what it means for a "company's structure, culture, capabilities, and management" (p. 88). PSS would thus have further-reaching consequences than can be seen on the economic/environmental axis. Baines et al. (2007) and Boehm et al. (2013) criticized the PSS literature that had been produced as vague, narrow, lacking in-depth, and lacking in empirical research. Boehm et al. (2013) also argued that PSS needs to be looked at from the innovation, organizational, and sustainability point of view in addition to the environmental impact/economic value point of view. All in all, the scientific literature has not satisfyingly been able to present a full picture of what PSS is, what is needed to implement PSS, and what the consequences are. Lind and Borg (2010) also expressed concern that large-scale construction projects with a service-oriented approach limit competition and therefore raise costs and there is little to no empirical proof that bundling maintenance and operations with the construction leads to efficiency gains because contractor's departments do not efficiently share information, nor is a private party necessarily better equipped to work more efficiently if the authority in question has extensive experience in maintenance and operation.
Many of the large industrial companies providing an integrated system of products and services have a large presence of existing products in the market. Rolls-Royce, a supplier of jet engines, saw that there is ten times the amount of engines in use by clients in comparison to their yearly sales. This gave them a large existing market for providing services in combination with the products (jet engines) (Smith, 2013).

According to Smith (2013), a PSS can be successful when the following attributes are present:

- Highly technical products
- Significant use of energy or need for maintenance in the operation phase
- A large fleet of existing products, making the move towards services attractive for supplier
- A feedback loop between products and services to continuously be able to improve the system
- Integration between product and service
- The system provides a larger value to clients than the respective individual parts

2.6 Other types of functionally specified systems:

Here the similarities and differences in an infrastructure context of yet another set of service-oriented approaches are shown. These are not inherently different from the above-mentioned examples, but they are elaborated because they are often mentioned in the same scientific articles and concepts that are distinctly independent. Figure 6 shows they are linked together as part of the theory on servicizing.

2.6.1 Performance-based contracting (PBC):

PBC is sometimes mentioned together with PSS, while other literature strictly focuses on one of the two aspects. The performance dimension in PSS is however most always present (Elmazoski et al., 2016; Tukker, 2004; Van Ostaeyen et al., 2013). Elmazoski et al. (2016) describe the PSS aspect as the "flow of products and services", while the PBC regulates the "flow of rights and duties". PSS thus specifically concerns the integrated system of product and service, while the PBC regulates what this system has to do and what it will be compensated for. A PBC can also be set up solely for a service, whereby no product is specified or needed.

2.6.2 Procurement of complex performance (PCP):

PCP is a line of research that concerns the procurement of functional performance. Hartmann, Roehrich, Fredriksen & Davies (2014) explored the transition from procuring individual products or services to procuring integrated systems, a PSS, although not explicitly mentioned. The authors stressed the importance of co-creating value as a client and contractor. Capabilities need to be built both in terms of contractual and relational capabilities. Thus, how are contracts written with functional performance requirements, while also eliminating opportunism by the supplier (or client)? It is not simply a matter of setting a highly abstract performance requirement; parties also perceive requirements differently. An example was a requirement of 'a clean road', what does that mean? Another study emphasized the importance of proper key performance indicators (KPIs); Schiphol procured Light-as-a-Service based only on W/m^2, while not specifying the quality of the light, which would have improved the value of the system (Duffhues, 2016). Hartmann et al. (2014) further divide the performance into the efficiency of an asset and the effectiveness of an asset. This is an important distinction that clients will have to make; do they want the supplier to make the current system as efficient as possible or should they also let the supplier be responsible for whether or not the current system effectively delivers value? This can be translated to 'is my pump running as efficiently as possible?' and 'Is a pump the most effective way of removing water?'. Another important aspect is how much of a system is integrated under just one supplier. This decision is be based on the needs of the client and the capabilities of the supplier (specific or broad portfolio of services).

2.6.3 Energy-Service company (ESCo):

ESCos are either private or public utility companies that take on the energy supply of traditionally a building. They are often paid the same amount as the customer was previously paying for energy, but they are encouraged to create additional energy savings through improved insulation, other energy forms, and better climate equipment. This benefit is then shared between the customer and the energy ESCo.

2.6.4 DBFM:

In comparison to PSS, DBFM(O) is a project delivery model, thus used for the delivery of a customized asset that still needs to be designed. It includes many of the same aspects of PSS, most notably specifications are functional. The interviewees often pondered what the essential difference is between a DBFM project and a Product-as-a-Service model. The way a DBFM project is set up in the Netherlands, it concerns infrastructure with a budget of over 60 million euros and a Special Purpose Vehicle (SPV) is set up for the financing of the project. Contractors of a tender take a minority stake in the SPV with some equity of their own. The power to control the project however lies with the banks that provide the loans for the project. A DBFM, which clients sometimes see as a way of fostering innovation by giving contractors the freedom to decide how to execute a project, actually only leads to efficiency improvements in the work-order and planning by the contractor. In the Netherlands, the DBFM project delivery model has seen an improvement with on-time and on-budget delivery of large infrastructure projects, however, DBFM and any Public-Private Partnership (PPP) project delivery model for that matter, has not seen significant innovation on the product and process development (Himmel & Siemiatycki, 2017).

2.7 Characteristics of the infrastructure sector

The infrastructure sector differs significantly from the sectors that are most often mentioned in the scientific literature on servicizing and PSS, such as the consumer and business-to-business market. Tenders and purchase decisions are also mostly done on a project basis, which often requires a customized solution. Innovative solutions are therefore not always scalable (Arnoldussen et al., 2017). Markard (2011) presented seven key characteristics that have implications for innovation in the infrastructure sector. Because infrastructure provides the fundamental services needed for a society to function, changes in this sector have both far-reaching consequences, but also present a significant barrier to any system-level change. The seven characteristics that affect the change of the infrastructure sector are (Markard, 2011):

1 Capital intensity
2 Asset durability
3 Environmental impacts
4 Systemness
5 Public organizations
6 Regulation intensity
7 Competition intensity

The degree to which each of the characteristics is a barrier to change also depends on the type of infrastructure. A centralized sewer network for example has higher asset durability than telecom networks. Some types of infrastructure projects also have much larger effects on the environment than others and are therefore also more heavily regulated. Also, infrastructure research has varying perspectives. The perspectives presented by Markard (2011) are technological, regulatory, and managerial. A PSS introduced for an infrastructure project also likely needs to meet objectives not only from a technological (e.g. lower environmental impact) but also from the regulatory (e.g. natural monopoly) and managerial (e.g. asset management) perspective.

All of these characteristics also impact PSS within the infrastructure sector, whereby likely capital intensity and asset durability create the biggest challenges for PaaS in the infrastructure sector. Many of the characteristics of the sector are characteristics that hinder rather than stimulate change within the sector. However, failing to take these into account will likely render a concept unusable in the infrastructure sector. In addition to these seven characteristics, the often custom-made project approach in infrastructure also complicated innovation and makes innovative products and services less scalable than e.g. in the ICT-sector where an additional product or service, once developed, can be produced at almost no additional cost (Arnoldussen et al., 2017).

Tabel 2.1 The seven characteristics of the infrastructure sector elaborated

Capital intensity implies that capital costs form a big share of the total costs of providing a service. This may make it less appealing to invest in a project if the capital can earn a better return on an alternative project. Markard (2011) estimates capital intensity very high for fixed costs above 60% and high for fixed costs of around 30%.
Asset durability means that assets have a relatively long-life span stretching for decades and big civil infrastructure, such as bridges, for a century. This also generally means that the technology advances slower than if the assets are less durable. Arnoldussen et al. (2017), recommends that public clients or the government, create a vision for how they see the infrastructure evolving over e.g. the next 50 years for private parties to come up with solutions and adjust themselves to the upcoming changes. However, predicting long term needs remains a challenge. For example, the weight on one axle by trucks has increased faster than the traffic load, due to efforts to save fuel, which has led to larger than designed point loads on bridges. This evolvement was not foreseen when many of the large bridges were constructed in the 1960s and 70s. This is to show that even if a circular viaduct, as designed by Rijkswaterstaat, had a lifespan of 200 years and could be demounted and used over and over again, it could become useless in a much shorter period if other things change in society. Markard (2011) estimates a very high lifetime at 50 years and a high lifetime at 20 years.
Environmental impact indicates that the construction of infrastructure and the use of it harms the environment. This impact can be local or global and temporary or permanent. Local temporary impact on the environment is often due to construction, while an example of global permanent damage is caused by greenhouse gases from power plants during the operational phase. When calculated costs related to the environmental impact are significant in comparison to the cost of using the service, the environmental impact is high according to Markard (2011).
Public organizations in this context influence transformation through 'decision rights' (p. 15). Investment decisions, pricing of output, and taxation are often decided by public organizations. In the Dutch infrastructure sector organizations that directly make decisions are RWS, provincial and municipal authorities as well as water boards that finance their infrastructure projects directly through taxes. Public organizations also differ from the private sector companies in that they are often politically motivated and financial incentives are not always the leading cause for a project to be initiated. If public organizations or utilities are supplying most of the services, the degree of public organizations is high (Markard, 2011).
Regulation intensity implies how much regulation applies to a sector in addition to general competition policy. Infrastructure projects are often highly regulated on safety, environmental impact, and pricing (due to natural monopolies resulting from a high capital intensity). The larger the project, and the more important it is for the general functioning of society, the more rules and regulations often apply, accompanied by significant safety margins on technical aspects, such as with the flood defense infrastructure in the Netherlands. Infrastructure projects also need to adhere to EU regulation on public infrastructure projects, of which Article 18 of the Directive 2014/23/EU of the European Parliament and of the Council of 26 February 2014 on the Award of Concession Contracts has the most impact on a service-oriented approach stating that: "1. The duration of concessions shall be limited. The contracting authority or contracting entity shall estimate the duration on the basis of the works or services requested. 2. For concessions lasting more than five years, the maximum duration of the concession shall not exceed the time that a concessionaire could reasonably be expected to take to recoup the investments made in operating the works or services together with a return on invested capital taking into account the investments required to achieve the specific contractual objectives." Therefore, public authorities do have stricter rules to adhere to when financing infrastructure projects. According to Arnoldussen et al. (2017), the sector sees the awarding rules as one of the biggest barriers to innovation in the sector. However, according to the authors, it remains unclear whether this is due to rules and regulations or whether the sector does not know how to efficiently use the currently available tendering techniques. Markard (2011) states that quality, grid access, safety, and environmental issues makes it highly regulated, while also regulating the service price makes it very highly regulated. Low regulation concerns areas with only competition regulation. Most of the Dutch infrastructure services supplied to the public have at least a partly regulated service price.
Competition intensity relates to the number of suppliers, the switching rates (how often and easily one can switch supplier), and barriers to market entry. A part of this characteristic is also how the value chain is organized, i.e. is one provider responsible for the complete service delivery (e.g. drinking water provider), or is it divided either vertically or horizontally (Dutch passenger rail transport – ProRail rails & NS trains). If the consumer can switch between suppliers the competition intensity is high, while if there is only one supplier in a regulated natural monopoly, the competition intensity is low (Markard, 2011).
Systemness is the last dimension and a "systemic character entails that by changing one element, other elements have to adapt and change as well" (Markard, 2011, p. 18). Coordination between components is also critical for systems with a high degree of systemness. In general, it can be said that "electricity supply, railway transport, and telecommunication are characterized by strong interdependencies" (p. 18), while for example for road infrastructure the systemness is not as clear, although also present (Markard, 2011). According to Markard (2011), a part of the infrastructure sector has a high degree of systemness when critical functions exist. This is, for example, the case for the Dutch Delta Works.

2.8 Summary

Based on the literature on both servicizing and more specifically Product-Service Systems combined with key characteristics from the infrastructure sector, Table 2.2 shows what effects the characteristics of infrastructure are thought to have on a service-oriented approach.

Table 2.2 Comparison of infrastructure characteristics and influence of the service-oriented approach

Infrastructure characteristics	Influence on a service-oriented approach
Capital intensity	A large portion of the costs of service provision is due to the construction costs (setting up a PSS). For large projects, the capital intensity will play a key role in a decision to proceed (who will finance the project?).
Asset durability	The underlying 'product' has a very long life span in comparison to other sectors. Assets may be technically durable for much longer than they are functionally durable. Iteration cycles are long in general and improvements take a long time.
Environmental impacts	Large impact on the environment either locally or globally (or both). Reducing environmental impact is central to the theory of PSS.
Systemness	Suppliers have fewer degrees of freedom because the solution needs to fit within the existing system (unless a system-level change occurs). Radical improvement requires a complete system change.
Public organizations	Is the structure of the client's organization suitable for PSS? Can the public client purchase infrastructure from a combined budget (construction & maintenance)? Does the public client have the resources to oversee a PSS? Interests for the client might not be only cost-related.
Regulation intensity	Regulated by EU-directives on publicly financed infrastructure works (value above €5,3M).
Competition intensity	For large projects, there are only a handful of possible bidders, thus reducing competition. For the increased competition, reduce the size and capital costs.

More generally, the intention of a service-oriented approach from a material-use perspective is to slow down both the number of resources used as well as the speed at which they circulate in the sector. Environmental performance, and especially incentivizing circularity has been the most important driver of servicizing and PSS that followed. Figure 6, shows how the different theories are linked to each other, from the basic notion of reusing material resources to procure complex performance.

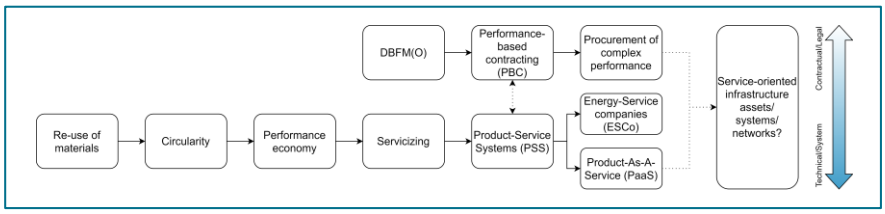


Figure 6 Theory development from re-use to service-oriented infrastructure

3

METHODOLOGY

3.1 Introduction

The challenge for this study is that a service-oriented approach has never been realized in the Netherlands, whereby a contractor or other private party would keep ownership of an infrastructure asset while supplying a public service. Therefore, there are also no applicable case studies or experts of servicizing in the field of infrastructure that could be interviewed for specific service-related questions. This study, therefore, takes a design-based exploratory approach, using a mixed methodology of the Double Diamond framework and grounded theory. The Double Diamond process gives a suitable framework for the steps to be taken in solving complex questions such as this one. It is developed by the British Design Council to aid designers and non-designers in a process of discovering, defining, developing, and delivering a solution or design (Design Council, 2019). The benefit of the double diamond framework is that it can be used for a broad range of problems and it is equally important to discover and define the problem as it is to develop and deliver a solution. Hence, the method is useful if part of the question is to explore the problem itself, which is the case. Figure 7 visually shows the four steps in the Double Diamond framework.

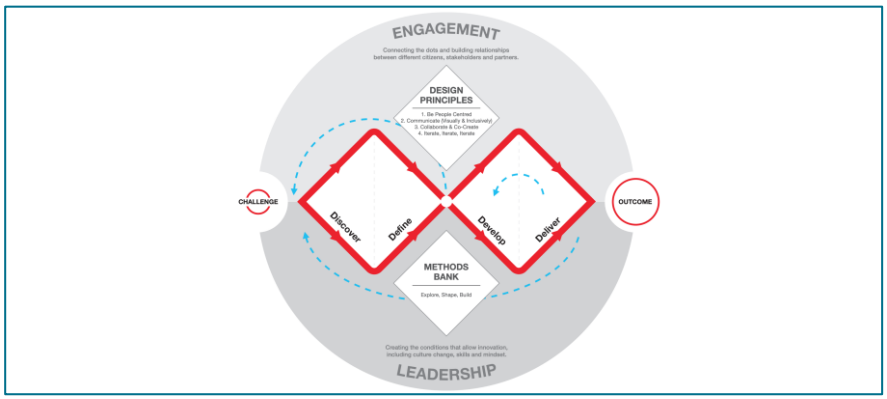


Figure 7 Double Diamond process as presented by the British Design Council (Design Council, 2019)

The Double Diamond has a double process of diverging followed by converging, hence the name 'Double Diamond'. The first diamond has a discovery phase where one is to understand the problem and a definition phase to define the challenge ahead. The second diamond has a developing where clearly defined problems are answered to develop the solution that is tested in the delivery phase. In the following subchapters, the phases will be elaborated in more detail. In this study, the first diamond will be focused on discovering what elements are important for a service-oriented approach while the second diamond will be focused on the process of assessing infrastructure assets based on the elements found in the first diamond.

While the Double Diamond framework visualizes the design process, the *grounded theory* methodology will be used to analyze and process the empirical data that is being collected throughout the research, to construct a theory. The method is elaborated in more detail in 3.6.

3.2 Discover (understanding problem)

For the discovery phase, experts on infrastructure assets within Witteveen+Bos will be interviewed in an exploratory setting, to get an understanding of what the consequences for a service-oriented approach are. The seven characteristics mentioned in 2.7 will be used as a blueprint for preparing the interview protocol (Appendix III). The focus in the interviews will be on the consequences that a service-oriented approach has for the infrastructure assets, but the project procedures will also be explored if the expert has insights to share.

3.2.1 Preparing the interviews

Current State-of-the-Art in circular contracting

As preparation for the expert interviews for the discovery phase, an exploratory interview is held with circular contracting expert Michel Berghuis to get an understanding of what the current state-of-the-art circular procurement looks like in the Netherlands.

Circular contracting for infrastructure projects at the time of this study is concentrated on technical specifications (M. Berghuis, personal communication, April 10, 2020). Bridge renewal projects are abundant in the Netherlands and they are the focus of many circular projects initiated by the public sector. The industry has agreed on an NTA agreement (Nederlands Technische Afspraak, a lighter version of a Dutch building-standard (NEN), which stipulates how interphase parts are built to allow for disassembly and reuse (Groot et al., 2017; NEN, 2017). The flow of materials is based on current circular capabilities, which means that technical innovations are not necessary to achieve the described circularity goals. A preferred way of tendering a project in the current setting is to enter a negotiated procedure where price initially does not play a role. Based on the ideas and capabilities to produce a circular design a contractor is chosen. Currently, the Dutch Design & Build contract (UAVgc) is used as a contract for the project once it has been awarded.

To evaluate the environmental impact of plans an analysis is made based on an Environmental Cost Indicator (ECI) in the Dutch infrastructure sector. It is a type of Life-Cycle Analysis (LCA) tool that takes into account not only the environmental impact of materials used for certain measurable categories but also the effects of transportation and production. However, this calculation is made for only one cycle and so the possible reuse of materials does not impact the ECI calculation for the initial construction (M. Berghuis, personal communication, April 10, 2020). The ability to analyze the impact of many use-cycles could be important to assess a service-oriented approach in comparison to a reference design based on a traditional approach.

Furthermore, to prepare for the interviews on specific assets, some details on procurement procedures and the type of public clients were also discussed. For infrastructure, a division can be made between Rijkswaterstaat that thinks more strategically over infrastructure assets (how can a highway network add to the accessibility of a region) and municipalities on the other end of the spectrum that look at a particular object and make decisions based on reference designs. Regional authorities such as the provinces and water boards fall somewhere in between, as they need to manage networks, but they also tend to work more on the object level. As this study looks at specific asset types, the focus will be on local and regional public clients.

Interview guide

The interviews aim to explore what elements are important when assessing the feasibility of a service-oriented approach. The guide is sent to participants before the interview together with an infographic (Appendix III) explaining the theory of a service-oriented approach. The term 'As-A-Service' will be used during the interviews, rather than 'service-oriented approach' because the general public is more familiar with that term. It is important to keep in mind that the participants are mostly technical experts of infrastructure and less familiar with the contractual and procurement side of public infrastructure. The seven characteristics of infrastructure serve as the basis, but the guide is further filled out with other concepts, such as modularity, circularity, and functional procurement, as these elements are important according to the literature on product-service systems (Huizing, 2019).

3.2.2 Data collection

Interviews will be used as the method of data collection on the viability of a service-oriented for Dutch infrastructure assets because the concept is still at its infancy when it comes to the infrastructure sector and there are no case studies to be made on projects that have been completed. The interviews will be held digitally due to the social distancing requirement because of the Covid-19 pandemic.

The interviews will be semi-structured to get answers on specific aspects, while at the same time being open for a broader discussion on topics related to a service-oriented approach, but that fall outside the specific characteristics mentioned in 2.7. Interviews are used because of the exploratory nature of this study. In the interviews, the researcher and the experts can look at the service-oriented approach from different angles, and it gives the researcher a broader view of what a public client needs to think about when deciding on the type of project delivery model to use for a specific project.

According to Stuckey (2013), interviewing experts within a certain field allows for collecting qualitative data, which can be used for making an assessment framework based on expert knowledge. According to DeMarrais & Lapan (2004), qualitative interviews allow for a detailed analysis of a particular topic or phenomenon, which is a useful step to take when there are large gaps in the understanding of how a service-oriented approach would fit into infrastructure projects.

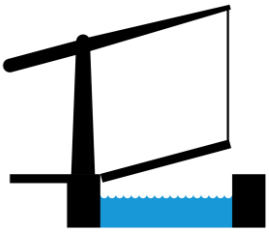
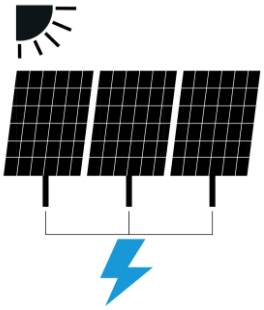
Interviews are conversations between a researcher and a participant or a group of participants, in this case, experts on a certain type of infrastructure. It differs from an everyday conversation in its intent to collect data for a specific study (DeMarrais & Lapan, 2004). The interviews for the discovery phase will be semi-structured. The interview protocol (Appendix III) is used to steer the conversation, but not limit the interviewee to only answering specific questions. The guide will also allow for "reliable, comparable qualitative data" (Stuckey, 2013, p. 57). This approach allows the interviewee to add more detail into their answer and to approach it from a different viewpoint than the researcher had planned for, giving more depth and insight into the answers. The method of "snowball sampling" (David & Sutton, 2003, p. 80) will also be used due to the limited beforehand knowledge available on this subject. The method implies that one interview is used as input for the next interview and also used for finding additional suitable participants.

3.2.3 Infrastructure asset types

Physical infrastructure is a wide notion, which implies everything from telecommunication to water treatment plants and energy generation. To collect in-depth knowledge, certain types of infrastructure will be explored in the interviews. As mentioned in the introduction, public infrastructure is facing several challenges over the coming decades: Aging infrastructure; water safety due to climate change; and a transition towards renewable energy generation. The accessibility of data for this study also plays a role in the decision on what type of infrastructure to focus on. The research will be focused on main infrastructure objects and subparts thereof, to explore the consequences for a service-oriented approach for specific infrastructure assets. With a broader view, the focus would be on larger connections and networks, area plans and nationwide accessibility (road infrastructure), rather than the specifics of certain infrastructure (Berghuis, 2020).

Table 3.1 shows the asset types chosen for this study. They reflect the type of infrastructure that is readily available in the Netherlands, and in which there have been some attempts of sustainability in all its forms. The study will focus on moveable bridges, pumping stations, and photovoltaic energy systems linked to infrastructure. There is expert knowledge within Witteveen+Bos for all the three types of infrastructure objects, to secure access to data and experts.

Table 3.1 Types of infrastructure assets being researched

3.2.4 Moveable bridges	In the Netherlands, there are more than 1500 moveable bridges. They are owned by different levels of government. A large part of bridges are built-in in the 1960s and 70s and are now reaching the end of their expected service-life and therefore form part of the renewal and renovation challenged, mentioned in Chapter 1 (Waterkaart, 2018).	
3.2.5 Pumping stations	There are about 1850 pumping stations currently in use by water boards, municipalities, provinces, and the government. They are the main tool for water management in the Netherlands (de Nederlandse Gemalenstichting, 2020).	
3.2.6 PV Systems	The capacity of the Dutch solar panels according to CBS (2019), was 4414 megawatt in 2018 (households 2307 megawatt and companies 2106 megawatt). This translates to about 15 million panels, with an expected service life of 30 years.	

3.2.7 Choice of experts

Senior employees with decades of experience working with certain infrastructure objects will be asked to be interviewed first, and based on the method of snowball sampling, additional experts are asked to participate. At least three experts for each type of object are interviewed for a robust “investigator triangulation” (Carter et al., 2014, p. 545) and to develop a “comprehensive understanding” (p.545). By doing this, different insights can arise as all participants of this study are affected by their personal bias. The effect of personal bias is reduced if multiple experts give similar answers and saturation of the answers take place.

3.3 Define (challenge ahead)

In the define phase, the interviews are transcribed, then condensed into 'meaning units' (p.94) and elements of importance are coded to transform the interviews into pieces of data that can be included in an assessment framework (Erlingsson & Brysiewicz, 2017). The first-order coding taking place is inductive and descriptive, meaning the coding is based on the meaning units themselves and is attempting to describe the phenomenon (Linneberg & Korsgaard, 2019; Erlingsson & Brysiewicz, 2017). For this phase, the results must be marked and traceable to the specific interview to guarantee replicability, which is part of validating scientific discovery. The transcribed interviews are first divided up into Aguinis & Solarino (2019) give twelve transparency criteria of qualitative research to guarantee transparency and replicability (Table 3.2). The replicability can also be divided into exact, empirical, and conceptual replication. The types of replication are important for further studies of the same topic and for validating findings from previous studies (such as Huizing, 2019).

Table 3.2 An adapted version of transparency criterion (Aquinis & Solarino, 2019)

Transparency criterion	Definition	Importance for:		
		Exact replication	Empirical replication	Conceptual replication
1 Kind of qualitative method	Qualitative methodology used in the study	√	√	
2 Research setting	The physical, social and cultural milieu of the study	√		√
3 Position of the researcher in the insider-outsider continuum	Researcher's relationship with the organization and study participants	√		√
4 Sampling procedures	The procedures to select participants or cases for the study	√		√
5 The relative importance of the participants/cases	The study's sample and the relative importance of each participant	√		√
6 Documenting interactions with participants	The transcription of the interviews	√	√	
7 Saturation point	When no new insights or themes are discovered in data collection and conclusion	√	√	
8 Unexpected opportunities, challenges, and other events	Additional sources of data, challenges due to participants suddenly declining, unexpected events	√	√	
9 Management of power imbalance	Differential exercise of control, influence or authority during the research process	√	√	
10 Data coding and first-order coding	The process by which data is categorized to facilitate further analysis	√	√	
11 Data analysis and second- and higher-order codes	Classification and interpretation to make statements about implicit and explicit dimensions	√	√	
12 Data disclosure	Raw materials collected by the researcher before any manipulation	√		

3.4 Develop (clearly defined problems)

In the *develop* phase, the coded data is developed into an assessment framework, which aims to guide a public client in the decision on whether to proceed with a service-oriented approach. The assessment framework should present a structured way of analyzing the proposed service-oriented approach, with the aim of as quickly as possible being able to decide on the feasibility. Additional studies take time, often months to complete, but they are often beneficial for public clients as they offer them some surety over the chosen path. The benefits of analyzing a project usually outweigh the delay of construction, because changes in later stages of construction are much more costly (M. Berghuis, personal communication, April 10, 2020).

3.4.1 Assessment framework

Before plans are drawn and people, resources, and financial means are committed to a project, it would be beneficial to know what the chances of success are. Some paths are more promising than others. Assets in the infrastructure sector are often built through projects that have a serious of stages, starting from the initiation phase when and ending at the completion phase (Ministerie van Financiën, 2013; Rijkswaterstaat, 2020). At the initiation phase, plans are made for what participants would like to achieve and in the next step, the exploration phase, a most successful course of action is chosen to work it out in detail in the planning phase. This study aims to develop an assessment framework to be used in the exploration phase to assess the viability of a service-oriented approach to realize the project or goals set in the initiation phase (Figure 8).

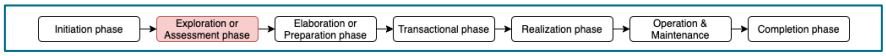


Figure 8 The context of the assessment framework in the timeline of a project (Ministerie van Financïen, 2013)

Several assessment frameworks have been published for Dutch infrastructure projects and they serve as a guide for how to develop the assessment framework presented in this study (Greef, 2006; Ministerie van Financiën, 2013; Unie van Waterschappen et al., 2017; Vliet, 2013). The Public-Private Comparator developed by the Dutch Ministry of Finance has been used for almost two decades and according to the authors It has been of invaluable help in delivering more cost-efficient projects. The goals and the subject are different in this study, but the phase of the project (Figure 8) and sector are identical, hence it serves as a good starting point.

3.5 Deliver (test on a small scale)

In the last phase of the Double Diamond method, the assessment framework will be validated on clarity and usefulness through an interview with a procurement expert from a public. The assessment framework will be updated based on insights from the interview that is relevant to the assessment framework.

3.6 Analyzing the data - Grounded theory

While the Double Diamond framework visually shows the process, it does not fully capture the scientific analysis taking place within the two diamonds. The grounded theory methodology is being used to systematically analyze the data, using a generally accepted methodology for qualitative research. The grounded theory fits very well for this specific study because it uses the analyzed data to construct a theory, grounded in the data collected by the researcher (Chun Tie et al., 2019). Grounded theory can be approached in several different ways, this study will use the process of initial, intermediate, and advanced coding as presented by Birks & Mills (2015). By clearly documenting the steps of analyzing the data from the interviews, a theory can be constructed with qualitative data without only one right solution. The findings will be influenced by the research setting and the researcher's background, but through transparent documentation, the grounded theory methodology forms a solid basis. Figure 9 shows how the methodology of grounded theory is used to analyze and codify the empirical data in this study and how it relates to the phases of the Double Diamond.

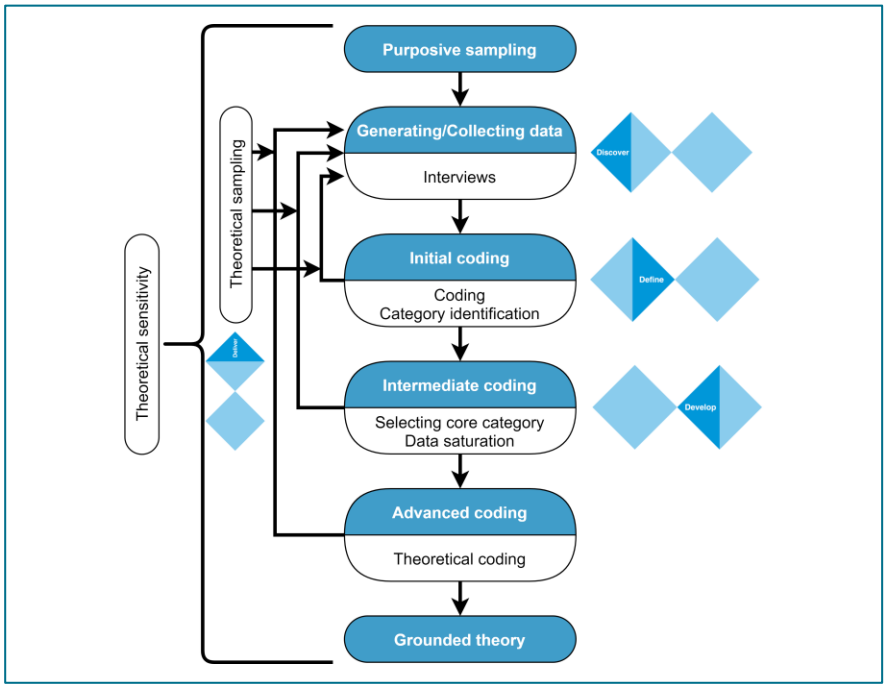


Figure 9 A modified grounded theory framework including the phases of the Double Diamond framework (Chun Tie et al., 2019)

"Regardless of the philosophical and methodological approach used to guide a study, the credibility of the research outcomes is dependent on the researcher employing the measures to ensure quality throughout the entire process. In other words, you must be able to demonstrate rigor in the conduct of your research." (Birks & Mills, 2015, p. 33)

3.7 Summary

This chapter presented the Double Diamond method, the methodology of the study. It discussed what will be done at each phase of the two diamonds. First, in the *discover* phase, experts of three types of infrastructure assets (moveable bridges, pumping stations & PV systems) will be interviewed in a semi-structured setting, guided by an interview protocol, to collect qualitative data. Second, the results from the interviews will be codified to group data into larger elements and to draw conclusions on which insights are most important for the third phase. In the development phase, the assessment framework is developed using existing frameworks for infrastructure decision-making as a basis, by consulting with this study's supervisors and by connecting data from the interviews where applicable. Last, a validation of the assessment framework will be done with a procurement expert from a public client, to test the clarity and usefulness of the framework. If a suitable asset can be found to test the framework, within the timeframe of the study, it would have a positive impact on the validity of the findings.

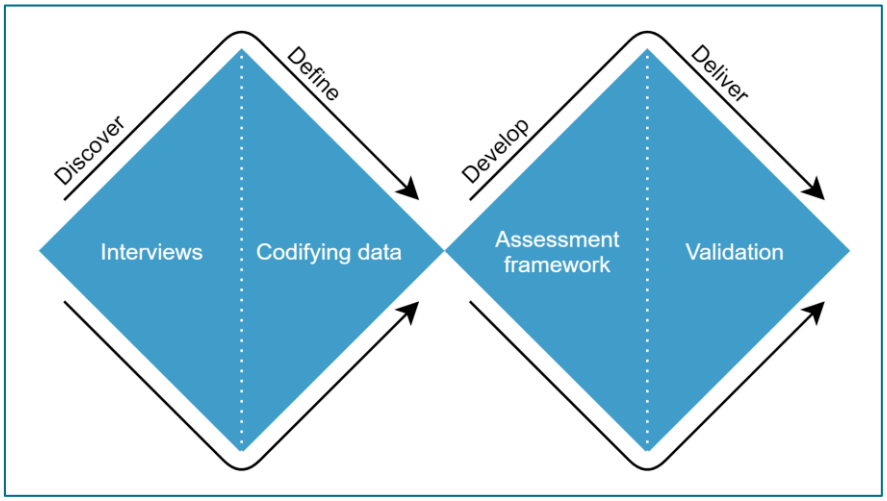


Figure 10 The steps in the Double Diamond methodology

4

RESULTS

4.1 Introduction

In this chapter, results are presented according to the methodology of the study following the phases of the Double Diamond. First, the specific characteristics of each type of infrastructure asset are presented, thereafter the consequences of a service-oriented approach. Additional components of a service-oriented approach and there impact on the feasibility of a service-oriented approach are also discussed. In 4.3, these elements are codified and grouped into larger entities to be used for the next step. Using the insights from the interviews as input, the assessment framework is developed according to 3.4.1, followed by the outcome of the validation round. A total of nine interviews are held, eight for the Discover phase, and one for the Deliver phase. The process of developing the assessment framework can be seen in Figure 11, including the four steps of the Double Diamond method.

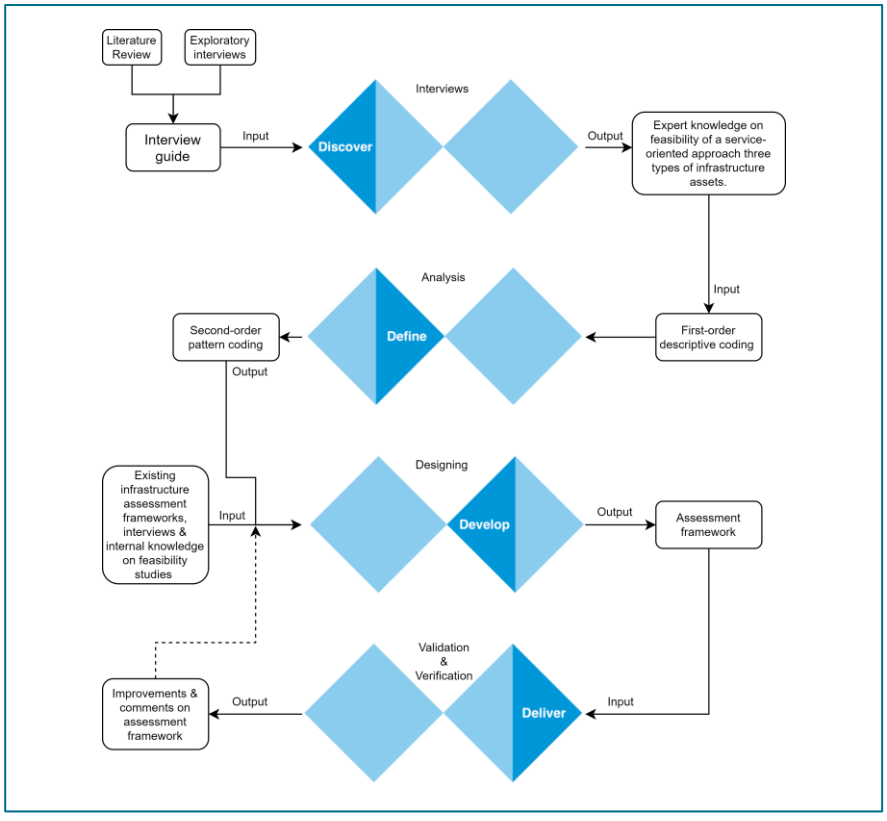


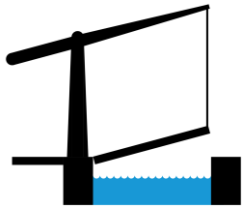
Figure 11 Flow of design process

4.2 Discover - Results from the first set of interviews

In this subchapter, the particularities of each type of infrastructure asset type are discussed, based on the key characteristics of infrastructure (see 2.7). Furthermore, the results of the interviews are descriptively codified and further elaborated. Table 4.1 shows the knowledge and experience of the participants of the Discover phase. Each interview took between 45 minutes and 1 hour 15 minutes, depending on how familiar the participant was with As-A-Service (elaboration of the concept needed) and how much he or she had to say about each topic. The interviews ended with a discussion of whether or not the participant knew another expert with suitable knowledge and experience (snowballing). The interviews were recorded, transcribed, and then condensed into meaning units (**Error! Reference source not found.** I) to make the codifying transparent and easy to follow.

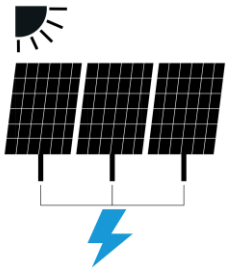
Table 4.1 Participant details for discover phase (area of knowledge & experience)

1	Moveable bridges	18 years of experience with moveable bridges. Currently an integral project manager. Experience with research, design, planning, contracting, procurement, and assessment of bridge infrastructure.
2	Moveable bridges	18 years of experience renting and selling standardized modular bridges to public authorities, construction contractors, and national defense.
3	Moveable bridges & PV systems	7 years of experience with sustainable energy and smart infrastructure systems. 5 years of experience with the integration of PV systems and infrastructure (bridges, locks, and tunnels).
4	PV systems	10 years of experience as a project manager of sustainable energy projects. 2 years (2 projects) of experience with PV systems in critical infrastructure. Managed PV system projects for drinking water companies and water boards.
5	PV systems	5 years of experience as an advisor of sustainable energy with a specialization in PV systems. Mostly feasibility studies for area development projects.
6	Pumping stations	More than 25 years of experience with pumping stations. Specialized in contracting and procurement and supervision of construction projects of pumping stations. Experience from more than 20 pumping stations projects.
7	Pumping stations	Wide experience with involvement in dike-, lock-, river widening- and pumping station projects. Worked in all phases of a project from feasibility studies to realization.
8	Pumping stations	3 years of experience, mostly from the energy transition. The graduation project concerned the future of pumping stations in the Netherlands. Experience from a few pumping station projects.



Moveable bridges

Pumping stations



PV systems

4.2.1 Moveable bridges

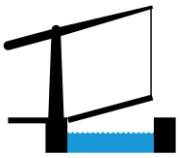


Table 4.2 discusses the findings for moveable bridges through the key characteristics of infrastructure. This information gives the context for the discussion (Chapter 5), to assess the feasibility across different types of infrastructure assets.

Table 4.2 Characteristics of moveable bridges

Capital Intensity	During a hundred-year service life of a bridge, a rough estimation of the capital intensity was given to be a ratio of about one-on-one in comparison to the maintenance and operational costs. The amount of maintenance needed during the service life could be greatly influenced through design choices made during the construction. A higher capital expenditure (CAPEX) could lead to lower operational and maintenance costs (OPEX) (excluding costs for the Bridgeman, safety, etc.) and vice versa. For moveable bridges, in particular, the maintenance is not equally divided over its service life with major maintenance needed at intervals of 5, 20, and 50 years. An important choice to be made that has consequences for the maintenance regime is the choice between a hydraulic or electromechanical engine to steer the movement of the bridge.
Asset Durability	A bridge and a moveable bridge in particular can be divided into subparts, which all have a different service life from each other. The software has the shortest theoretical service life as it is usually written off after 5 years. The electrical engineering parts have a theoretical service life of 15 years, the mechanical engineering parts an estimated 20-50 years (50 years for major mechanical parts of a moving bridge), and 100 years for the civil engineering structure. The durability of the asset currently reflects the rate of amortization in accounting terms, the subpart could very well continue to be both technically and functionally sound and is often not replaced immediately at the end of its theoretical service life. The design parameter that forms the basis for the service life calculation is the number of vehicle units passing the bridge. If a bridge is much more heavily passed in its service life, than initially could have been foreseen the service life in terms of years will likely not be reached.
Environmental Impacts	The environmental impact caused by moveable bridges can be divided into the construction and operational phase. During construction, greenhouse gases are emitted for transportation, constructing the foundation (concrete) and the steel structure. The construction also causes noise emission and affects the local ecosystem for various animals. In the Netherlands, the emission rights of nitrogen however need the most attention at the moment as the allowed threshold is currently extremely low on a local level. The steel structure, which is constructed off-site can have much higher emissions both in terms of CO2 and nitrogen-type emissions but is not subject to the same level of stringent regulation.
Systemness	The systemness of moveable bridges in the Netherlands is high both on an object level as well as on a network level. On an object-level, there is a high level of integration necessary and there is no one party that would be able to produce all the parts needed for a moveable bridge. What the engineers working on the Cruquius bridge are attempting to do, is to introduce a type of bridge where all the interphases are based on a standard, so that parts in the future can be exchanged between bridges.
Public organizations	All permanently installed moveable bridges in the Netherlands are owned and operated by public authorities, mostly on the provincial level in cooperation with the local water boards. The bridges can be operated either locally by a Bridgeman, or at a central operating center. Either way, the responsibility for the safety of the bridge users, both automobiles, cyclists, and pedestrians fall under the responsibility of public authorities. Public organizations also organize the maintenance, but the maintenance is carried out by private contractors. Currently, these organizations are very traditionally oriented and significant changes would have to take place for them to be aligned for a service-oriented approach, where infrastructure would be supplied by private parties. Many public clients have also already chosen an approach for the coming decades and they might be very reluctant to yet again try to implement a new way of procuring assets.
Regulation intensity	An important regulation that applies specifically to moveable bridges is the European machine directive 2006/42/EC as well as the requirement that all parts be CE marked. The moveable bridge is seen as a 'machine' in the eyes of the regulator, and it includes both technical as well as organizational requirements. The regulatory environment for moveable bridges is quite stable and predictable in the Netherlands, although the requirements on safety, accessibility, and reliability are continuously intensifying.
Competition intensity	Currently, there is one supplier of a moveable bridge-as-a-service type of PSS in the Netherlands. For the civil structure there are approximately 8 suppliers and for the steel structure a handful of suppliers. For a moveable bridge, it could be assumed that the steel structure supplier would be the main contractor. The industry of steel suppliers is however organized so that they preferably have filled their order books with production on just-in-time with minimal storage needed. Combining this with the as-a-service delivery model could face resistance among the steel suppliers as they would likely need to store additional parts or bridges, needing space, and requiring capital.

4.2.2 Pumping stations

Table 4.3 discusses the findings for pumping stations through the key characteristics of infrastructure. The participants spent a large portion of the time highlighting the type of public organizations that operate the pumping stations and the importance of statutory duties.

Table 4.3 Characteristics of pumping stations

Capital Intensity	Pumping stations have a relatively low capital intensity as the maintenance and operational costs equal the capital expenditure already after 10-20 years.
Asset Durability	Traditionally, pump stations are designed for a service life of 100 years. That means that they need to fulfill their designed task of keeping the water level at a certain height, taking into account subsidence and sea-level rise. The longevity of the assets depends on the amount of time that they need to pump water. Some minor pumping stations are only occasionally pumping, for example after rainfall, while others are continuously pumping. Mechanical parts have an estimated service life of 25-40 years, electrical installations about 15 years, and process automation (software) between 5 to 10 years. Water boards take great care of the pumping stations and most pumps reach far beyond the expected technical service life. Often a pump is renewed due to a functional reason (more capacity required), rather than due to a technical failure. There are three reasons why pumping stations are renewed and they are about equally common: 1 A pump reaches the end of its technical service life and to reduce the risk of failure a new pump is purchased, or because parts are no longer available. 2 Changing physiological conditions leading to a greater capacity need 3 A modern pump has lower operational and maintenance costs (a lower energy bill usually also means lower greenhouse gas emissions). The participants were not aware of any instances where assets would have been given a second life or built in a modular fashion, allowing for parts to be reused. Most contracts require new parts to be used for all the installations.
Environmental Impacts	The largest climate impact occurs during the operational phase and is due to the use of energy to run the pumps. Another effect that pumping stations have on the environment is that they 'grind' fish. The newest generation of pumps are more fish-friendly and additional regulation demands fish friendlier pumps
Systemness	The network of pumping stations is highly systematic. Changing the pumping regime at one station has effects on the other parts of the system. Sometimes pumping stations also serve an additional purpose, such as supplying heat or electricity to nearby industrial areas (Gemaal Vissering, Noordoostpolder). Some stations are centrally operated. Some degree of modularity of pumping stations can today already be seen, for example, some waterboards have a standardized housing for the pump. Increased standardization could also be achieved on the smaller scale pumps; ones that lift 1 m^3 of water about 1 m per second. These are considered small, and they are plentiful in the Netherlands.
Public organizations	All pumping stations in the Netherlands are operated by regional water boards. They are public organizations, their board members are chosen through elections and it is their statutory duty to guarantee water safety, water quality, and water quantity in the Netherlands. Water boards are also held accountable if they do not fulfill their tasks and a flood occurs, damaging crops of farmers or leading to flooded basements in households. These claims can reach millions of euros for a single flood. An example of a case where a water board has outsourced some operations is the wastewater treatment plant in Harnaschpolder. It was contracted as a DBFO to a consortium of which Evides Industriewater has a majority stake. Shareholders of Evides Industriewater are public authorities, municipalities and the province of Zeeland.
Regulation intensity	The regulation surrounding water management is stable and predictable in the Netherlands. Water boards have an important task of setting the water levels and changes in the water levels could change the preconditions of pumping capacity. Changes in the water levels mostly follow physical cycles however, and there are therefore predictable and are usually overseen on average every 25 years.
Competition intensity	Pumps form the heart of the pumping station and there are about 5 suppliers of the kind of pumps needed by municipalities. There is about a handful of suppliers of trash racks and trash rack cleaner and for the electrical engineering parts, there is another 6-7 suppliers and a total of 15-20 contractors that are capable of constructing a pumping station. However, the type of pump that is needed at each location requires customization and the preconditions limit the choice of the pump to usually a specific type of pump, with a specific capacity both in terms of height and cubic meters per second. There is a pilot project at the Noordoostpolder going on where the waterboard buys energy in bulk, a day in advance at the most affordable times the next day, for a specific amount of energy. This is done to reduce the energy bill of pumping stations.

4.2.3 Photovoltaic (PV) systems

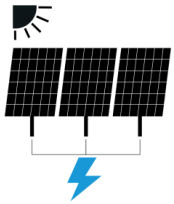


Table 4.4 discusses the findings for PV systems through the key characteristics of infrastructure. The findings are relevant only for PV systems connected to (critical) public infrastructure, as the requirements differ from that of private large solar fields and roofs.

Table 4.4 Characteristics of PV systems

Capital Intensity	The most capital-intensive part of a photovoltaic system is the solar panels. They make up about 30-50% of the total capital costs. The maintenance during the service life (25 years) of the system is approximately 10% of the capital costs and includes mainly cleaning the panels and renewing the inverters at 10-year intervals. The cost ratio inverters to panels are about 1:4. The PV system is a very capital intensive system with almost all costs made up-front and earned back throughout the service-life through a lower energy bill.
Asset Durability	The solar panels have a theoretical service life of 25 years after which they should still supply 80% of the energy at the onset. Solar panels normally do not suddenly malfunction, but rather their output decreases over time. The 25-year service life is also more of an estimate rather than a hard technical feature, as very few modern PV systems have reached that age. The inverters have a shorter service life as mentioned, but there are numerous panels connected to one inverter. Cables depreciate the quickest in accounting terms (5 years), while they usually remain intact throughout the service life of the system. Once again, the depreciation of assets in accounting terms does not align with the actual technical or functional service life.
Environmental Impacts	The most noticeable impact of panels is the space they take up. If panels are placed on roofs or other existing structures, the impact on space is minimal. Public authorities have to think decades ahead before going forward with a PV energy project as they might need the space at a later time. The panels also cast a shadow and thus limiting the ability of flora to grow in the same space. One topic that also came across was the impact reflections of the panels have on the navigational capabilities of specific birds. However, the evidence is not conclusively positive or negative. The panels also consist of many different materials, some of which are scarcer than others and also potentially harmful to the environment. There is currently an ongoing effort to start a recycling program for solar panels and a take-back requirement for panels at the end of their service life was going to be included in the tender for a PV system at a water treatment facility.
Systemness	The electricity network is highly systemic, but for the water treatment plant, the client had decided to keep the PV system separate from the main electricity supply to prevent disturbances and avoid risks related to mixing the two systems, such as that the emergency would not switch on when needed. The products themselves are highly standardized and always come in specific sizes.
Public organizations	Public organizations play a different role than in the two other asset types discussed previously. They are not responsible for producing energy or electricity, but they include PV energy systems more and more into the current infrastructure to set an example and meet the sustainability renewable energy goals set by their organizations. Such a system aims to be cost-neutral but the energy price for public authorities is a fraction of the cost to consumers, so that is not the main driver behind their willingness to exploit this type of infrastructure.
Regulation intensity	The regulatory environment is still somewhat unpredictable in the Netherlands when it comes to regulation on renewable energy and especially PV systems. Currently, there is a subsidy in place that is paid out over 15 years for the installation of a PV system. The rules and documentation are highly dependent on the type of location where the system is installed. Placing a PV system on a private field can be done with much lower regulatory involvement and less technical specifications than when the system is installed in combination with critical infrastructure such as water treatment plants, wastewater treatment plants or pumping stations, which in the Netherlands fall under critical infrastructure.
Competition intensity	The panels are highly standardized, both in terms of output and size, and the bulk comes mostly from China. Some specialized panels are produced within the European Union. Clients for critical infrastructure usually require that a traditional contractor with experience working for public clients take on the role of the main contractor, to make sure the contractor is familiar with the level of documentation and precision that is required when connecting a system to critical infrastructure.

4.3 Define - Analyzing and codifying interviews

According to the participants, the seven characteristics used for the interviews covered most of the aspects concerning a service-oriented approach and after going through the interview guide there was generally very little to add. However, the content of the answers provided by the participants covered a much wider set of characteristics and elements than the seven characteristics, which was the goal of using semi-structured interviews for empirical data collection. The condensed meaning units (Appendix I) were used as a basis for the first-order coding. A total of 35 additional elements are codified. The coding of elements is based on either more than one participant talking about a particular element, such as the RAMS aspect, or in case a participant emphasizes the importance of a unique element, it is also coded. An example of emphasis is the oversupply of electricity by PV systems mentioned by participant 5 and the different service-level offerings mentioned by participant 2. All of the 35 elements are presented and elaborated in Table 4.5.

Tabel 4.5 First-order codified elements

Elements associated with a service-oriented approach	Elaboration
Statutory duties	Local, regional, and national authorities have certain statutory duties. These duties are set by the Dutch government through legislation. Passing these duties on to private parties is questionable and difficult according to the infrastructure experts. Provinces are responsible for the construction and maintenance of provincial infrastructure; waterboards are responsible for water safety, quality, and quantity. When a public authority fails to meet the duties they are responsible for they may be subject to claims. For example, waterboards have to pay for damages to farmers and households caused by floods if a pump station fails (Faure & Maastrichts Europees Instituut voor Transnationaal Rechtswetenschappelijk Onderzoek, 1995). In the event of a disaster, the service supplier might go bankrupt and the residents would go uncompensated for the damage. In the case of pumping stations, the damages are usually economic, but with moveable bridges, the worst-case scenario is a loss of life, which cannot be insured. The Province of North Holland did outsource its bridge operators in 2017, but after several complaints on the service quality, the provincial authority is taking the operations back into its organization (Patrick Meershoek, 2020). [Interviews 1 & 6]
Life-cycle costing (LCC)	A service-oriented approach requires parties to think in terms of complete lifecycles. Life-cycle costing involves both the financial cost for the client as well as external costs, such as environmental costs and costs to the public. [Interview 1]
Functional specifications	Functional specifications are a part of a service-oriented approach in infrastructure. As part of giving the infrastructure market more design freedom, public clients are specifying
RAMS	Public clients are using RAMS aspects to monitor the performance of projects with functional requirements. The RAMS stands for reliability, availability, maintainability, and safety. For moveable bridges, the reliability would mean the probability of failure to open or close the bridge when requested. The availability aspect indicates the percentage that the bridge is available (no maintenance). Maintainability indicates the ease at which an asset can be maintained, how often it has to be maintained, and for how long. Safety implies the probability of an accident with injury or death as results, both users and operators. [Interview 1 & 7]
The total cost of ownership (TCO)	It was mentioned that public clients have generally understood the benefits of calculating the Total Cost of Ownership, rather than looking at only the construction costs. However, with infrastructure that lasts for decades, it is difficult to predict what exactly will happen over the coming decade or even century, in some cases. It seems unreasonable to let a private party take all the risk of uncertainty and in some cases, public authorities would have to pay a hefty premium for the risk. [Interview 1 & 6]
Risk	Public clients see the possibility that providers of infrastructure-as-a-service either supply a service that does not meet the performance criteria; that the service becomes unavailable due to bankruptcy; or that venture capitalists take over public infrastructure intending to earn as much money as possible rather than create public value. [Interview 1, 6 & 7]

Elements associated with a service-oriented approach	Elaboration
Liability	Public clients have certain statutory duties. If they are not able to live up to the requirements set by these duties they become liable for the damages. The question remains who is responsible if a private party is providing a service, which does not fulfill the performance requirements. In the worst-case scenario, the private party may go bankrupt due to claims and the victims do not receive any compensation. [Interview 1, 6 & 7]
Circularity	The service-oriented approach is seen as a way to incentivize a circular use of resources. As long as a supplier can fulfill the RAMS specifications the supplier should ideally be free to reuse assets to reduce the use of finite resources. In practice norms are constantly becoming more strict, meaning that older parts often cannot be used in new structures because they do not fulfill the most recent norms. The market and legislators should agree on how to allow for the reuse of parts, to make circularity possible. [Interview 1, 2, 3, 4, 5 & 7]
Supply in the market	There are currently very few suppliers of service-oriented infrastructure. As public clients largely determine what is supplied through public tenders, if they do not actively seek more service-oriented assets, the market would have to pre-emptively invest heavily in processes and products without being sure there is a demand for it. [Interview 1 & 2]
Return on investment	What the return on investment would be for a service-oriented approach will likely determine how many parties are interested in investing in service-oriented infrastructure. Parties that currently rent out infrastructure (bridges) earn back their investment (not accounting for R&D) within 2-3 years. This makes it interesting for them to invest in the asset. However, such a quick return on investment means that it is more beneficial for public clients to purchase assets rather than rent them (in the long run). PV systems are financed on the assumption that the investment is earned back in 15 years. Also, this is a rather quick return on the investment, assuming the panels have a lifetime of 25-30 years. Suppliers will likely invest in products and services that have the highest return on investment, civil infrastructure with a designed service life of 100 years likely is not such a business case. [Interview 1,2 & 5]
Stakeholders	Public clients take time to carefully plan how assets are realized. During the process, they make agreements with multiple stakeholders that are affected. A moveable bridge for example influences users of a shipping route, road users, nearby residents, and energy suppliers. This could mean agreements over a minimum height, certain opening times, a specific architectural design, and an energy supply. These agreements form the basis in a procurement process and are traditionally included in the construction and maintenance contracts. With a service-oriented approach, it becomes questionable how these agreements are guaranteed. Who should stakeholders approach if they feel that there is a breach of contract? And will there be more agreements necessary (and possible more disagreements) because stakeholders feel they have less influence once a private party takes over assets, rather than a public authority? This would be contrary to the idea that the supplier would get as much freedom as possible to realize the project. The new Environmental and Planning law regarding participation in the Netherlands is sure to make stakeholder involvement more complex and pervasive according to a participant. [Interview 1 & 8]
Knowledge of infrastructure systems	With a transfer of responsibilities to the private market, knowledge of how infrastructure systems work has also somewhat disappeared from public clients, while the decision powers have remained with the public clients. This leads to decisions being made without sufficient knowledge. Engineering consultancies have taken up some of the space between traditional contractors and public clients, to advise public clients. However, when setting functional requirements it is important to have sufficient knowledge of systems to avoid perverse incentives and loopholes that could lead to a different result than what the public clients aimed for. [Interview 1]
Long-term agreements	For suppliers to be able to earn back their (added) investment of an As-A-Service product, the contract duration needs to be longer than usual for performance-based contracts, only based on maintenance. This does incentivize a shift in thinking towards TCO, but at the same time, it creates uncertainty over the long run as the flexibility of both parties is reduced. Private companies do value a steady revenue flow, so this would likely be a bigger problem for public clients than private suppliers. [Interview 1 & 2]

Elements associated with a service-oriented approach	Elaboration
Modularity	For a service-oriented approach to be successful, infrastructure should become more modular. This would allow for modules to be procured and also removed in case the service is ended. NTA-agreements have been made for the interphases of moveable bridges in the Netherlands to make parts of bridges exchangeable and increase circularity (Technically it is not an agreement on modularity, but on how interphases are designed). Modularity is also used in the design phase of pumping stations to prepare for possible future expansion of pumping capacity. However, the degree of modularity continues to be low and e.g. the foundation is always a custom solution that cannot simply be removed and reused somewhere else. [Interview 1, 2, 5, 6 & 7]
Standardization	The industry is aiming to use more standardized parts. However, for decades the focus has been on fit-for-purpose designs and therefore a shift towards using standardized parts (which will lead to the use of over-dimensioned parts) goes contrary to the aim of engineering structures. Standardized dimensions are often used in construction, but for more complex structures there are not yet common agreements on what parts should be standardized and who would be able to produce them. In the ICT-industry, products have eventually become highly standardized and clients can use products from different suppliers interchangeably. In the beginning, certain suppliers only supplied systems that used parts that only they could produce. However, they had to adapt to a changing market. The infrastructure sector will likely undergo the same transformation towards standardized parts, but how this will happen remains unclear. Parties with a large share of the market and lots of market power, will likely also initially resist opening up the market for others to make parts that would fit into their systems. [Interview 1, 2, 5, 6 & 8]
Service-levels	Public clients need to think carefully about the service-level that they are aiming for. Different service levels could be agreed upon through the RAMS aspects. The more stringent the RAMS aspects are, the higher the service level. [Interview 2]
Customized solutions	Engineers, architects, and public clients alike have traditionally aimed for customized solutions. To make sense for suppliers to develop service-oriented assets, public clients would need to accept some form of standardization. This is likely to create some tension between stakeholders that want a recognizable and highly customized design and those that prefer the advantages of mass-production. [Interview 2]
Flexibility	A service-oriented approach can have two effects on flexibility. On one hand, the assets would likely be made removable/transferable in case a contract no longer is extended. This would give public clients more flexibility over future designs. On the other hand, entering into long-term agreements with private parties that are responsible for maintenance will reduce the budget flexibility of public clients as the assets will be maintained as agreed and clients will have to continue paying. A reason for asset management has been to increase the budget flexibility by allocating means for maintenance to where it is necessary, as maintenance budgets have always been short of what is needed for maintenance to take place as intended. [Interview 1 & 2]
Asset management	Asset management will play an important role if a shift towards service-orientation is to take place. Suppliers will have to know how parts have been used and how much of their designed service-life remains. For a supplier of bridges-as-a-service, a proper asset management protocol serves as the backbone of their business of renting out modular bridges. [Interview 2]
Maintenance	Maintenance is one of the main drivers of moving towards a service-oriented approach. By procuring service for a certain period, maintenance becomes an integral part of the service, rather than a separate action that needs to take place once a project has been realized. It also incentivizes the supplier to design assets so that they can be cost-efficiently maintained throughout their service life, which sometimes means additional pre-investments to reduce the need for maintenance later on. [Interview 1, 3, 4, 6 & 7]
Critical infrastructure	Infrastructure, which forms the backbone of a society and supplies basic needs, is deemed critical. Pumping stations, water treatment plants, and energy supply fall into this category. In the Netherlands, public authorities are the owners of such infrastructure. Generally, operation and maintenance are very detailed and the room for flexibility is limited. Public clients tend to choose for options whereby they have a large control of the systems and they are very reluctant to transfer responsibility to private parties. [Interview 3 & 4]

Elements associated with a service-oriented approach	Elaboration
Alternative financing	A service-oriented approach enables alternative financing. What the benefit of such models is, is still unclear. In general, pubic authorities can finance projects at lower costs than the private sector. [Interview 3]
Venture capitalism	Venture capital should not be used for infrastructure projects. Public infrastructure has to fulfill stringent quality, strength, and safety requirements and regulation outright ban excess income from public infrastructure. The bridge disaster in Genoa also highlights problems with private operation and maintenance of public infrastructure. Because companies can be bought and sold in a free market economy, the possibility of a supplier being taken over by a venture capitalist who has different goals than the original supplier had when the contract was signed, could lead to problems. [Interview 3 & 7]
Retain knowledge	A service-oriented approach would lead to market parties taking over more of the tasks originally places at public authorities. This shift would ultimately lead to some of the workforce moving to private parties. Interviewees had reservations on whether or not private parties have the ability to employ and retain highly skilled staff. The maintenance technicians at water boards have generally worked for decades at water boards and whether they would be willing to work for a private pumping station supplier is not clear. As long as the current knowledge by public authorities is transferred to private parties without a significant loss of knowledge, a switch towards a service-oriented approach should not necessarily have to cause problems for public infrastructure. [Interview 3 & 7]
Research and development	Through procurement, public authorities can allocate funds for research and development by requiring and paying for innovative solutions. With a service-oriented approach, parties are incentivized to cut down on costs as much as possible, as functional requirements are used to define the performance. Often innovation requires a specific inquiry on a specific problem, with some technical detailing. Simultaneously, research and development done by the supplier become an important part of the service, as the idea behind a service-oriented approach is to improve the service over time, through built-in feedback loops. [Interview 2 & 3]
Documentation	Public authorities, responsible for critical public infrastructure require a high level of detailed documentation of everything that is undertaken. For example, before contractors are allowed to place solar panels on the site of a water treatment plant, they need to show in detail how these panels are placed. Very few (mainly traditional contractors) are used to this level of documentation and would find it hard to supply the required documentation, to fulfill the requirements set by public authorities. This might limit the number of suppliers of a service-oriented asset. [Interview 4, 5 & 7]
Supplier warranty	Another solution for achieving the same goal of added supplier responsibility during the service life of assets is to require that suppliers give a warranty on their products. Some solar panels suppliers, for example, guarantee that their panels will give a certain output over 25-30 years. This makes a service-oriented approach less needed, as public clients are given a guaranteed service life for products. [Interview 5]
Permits	Public authorities have many tools at their disposal to achieve their policy goals. One of the strongest tools is the power to grant permits. Environmental goals can often be more efficiently achieved, by steering projects through permits, rather than procuring service-oriented assets. [Interview 5]
Oversupply	Especially for PV systems, oversupply can become a problem in the short term. Renewable energy projects that are realized for certain energy output, could supply this energy at the wrong moment, leading to an overload of the network. The network in the Netherlands will need an increased level of integration of suppliers and users so that demand and supply better match each other. Currently, the problem of oversupply is realized through the negative pricing of electricity during peak production times. This will make it more challenging to earn back investments made into renewable energy sources. The participant did not see a service-oriented approach as a solution to this problem, because of the high level of integration needed (one party would have to control the energy supply, industry, and home appliances). [Interview 5]
Optimization	The goal of a service-oriented approach is to optimize the use of resources. If one party is responsible for an asset throughout its lifetime, theoretically this gives an incentive to think about resources from a life-cycle point of view. [Interview 1 & 6]

Elements associated with a service-oriented approach	Elaboration
Contract duration	Contracts for service-oriented infrastructure assets need to be for a longer duration than current maintenance contracts. This is necessary to incentivize suppliers to design for the actual service-life of an asset and to make it feasible to earn back investments made upfront by the supplier. [Interview 1 & 7]
Public value	Public values are added value for the public at large (society), which does not directly financially benefit the asset supplier. Therefore, a supplier would not have an incentive to guarantee or improve public values, which has traditionally been a task for public authorities. [Interview 7]
Data	To optimize the asset, suppliers need data. For bridges, this can be traffic loads, especially heavy axial loads. Including sensors for each part in a bridge is not feasible, therefore suppliers would have to rely on data supplied in the procurement documentation. Water boards have only very recently started collecting data on the durability of small but crucial devices (e.g. water level meters that switch pumps on and off). [Interview 2 & 7]
Robust design	This element is especially applicable to water boards. Pumping stations are often 'over-designed', whereby authorities choose solutions that are the most long-lived without making a specific life-cycle analysis. This gives them a certain additional margin of safety. [Interview 7]
Contract types	The Dutch infrastructure sector uses several different contracts, UAV, UAVgc, Bouwteam, DBFM. According to participants DBFM has many of the same features as an As-A-Service contract. However, the purpose of a DBFM is primarily to optimize work- and building stages with each other as there is only one procurement. Innovative solutions concern mostly the workflow rather than physical objects. [Interview 8]

4.4 Develop - Classifying elements into criteria for the assessment framework

To be able to make an assessment, the codes from 4.3 should be categorized. The process of classifying the elements is iterative. Initially, similarities between elements are used to group them into larger units using *pattern coding* (Miles & Huberman, 2008). This allows for higher-order categories, which can be included in an assessment framework. According to participants 1 & 7, functional specifications and the RAMS aspects are suitable for a service-oriented approach. Therefore these will serve as a basis for determining the requirements that a public client has on an asset. The additional elements of the interviews were classified into six categories, which attempt to describe the common feature between the elements in the group. The *codes* form the individual ingredients in a recipe, while a *category* includes e.g. all 'dry' ingredients such as flour and baking powder. The assessment framework presented in 4.5 then forms the workflow side of the recipe, i.e. the order in which certain assessments are made. These categories are based on the process of intermediate coding (Figure 9), which is further elaborated in Figure 11, and are a part of the grounded theory methodology. Both the codes, the sense of what the participants emphasized in the interviews as well as the existing literature on a service-oriented approach were used to deductively construct the categories. Another requirement for each category is that it should be something that can be assessed in the exploration phase of a project. Not all codes are included in a category; these are codes that are of interest for a service-oriented approach but that are either irrelevant for the framework or too abstract to be able to qualitatively or quantitatively assess.

Table 4.6 Second-order coding - classifying codes into categories

Category	Code
Innovation 	• Knowledge of infrastructure systems • Retain knowledge • Research and Development • Data
Integrality 	• Modularity • Service-levels
Public accountability & ownership 	• Statutory duties • Liability • Stakeholders • Flexibility • Critical infrastructure • Permits
Supply 	• Supply in the market • Return on investment • Documentation • Supplier warranty
Circularity 	• Circularity • Standardization • Customized solutions • Asset management • Maintenance • Supplier warranty
Duration 	• Return on investment • Long-term agreements • Contract types

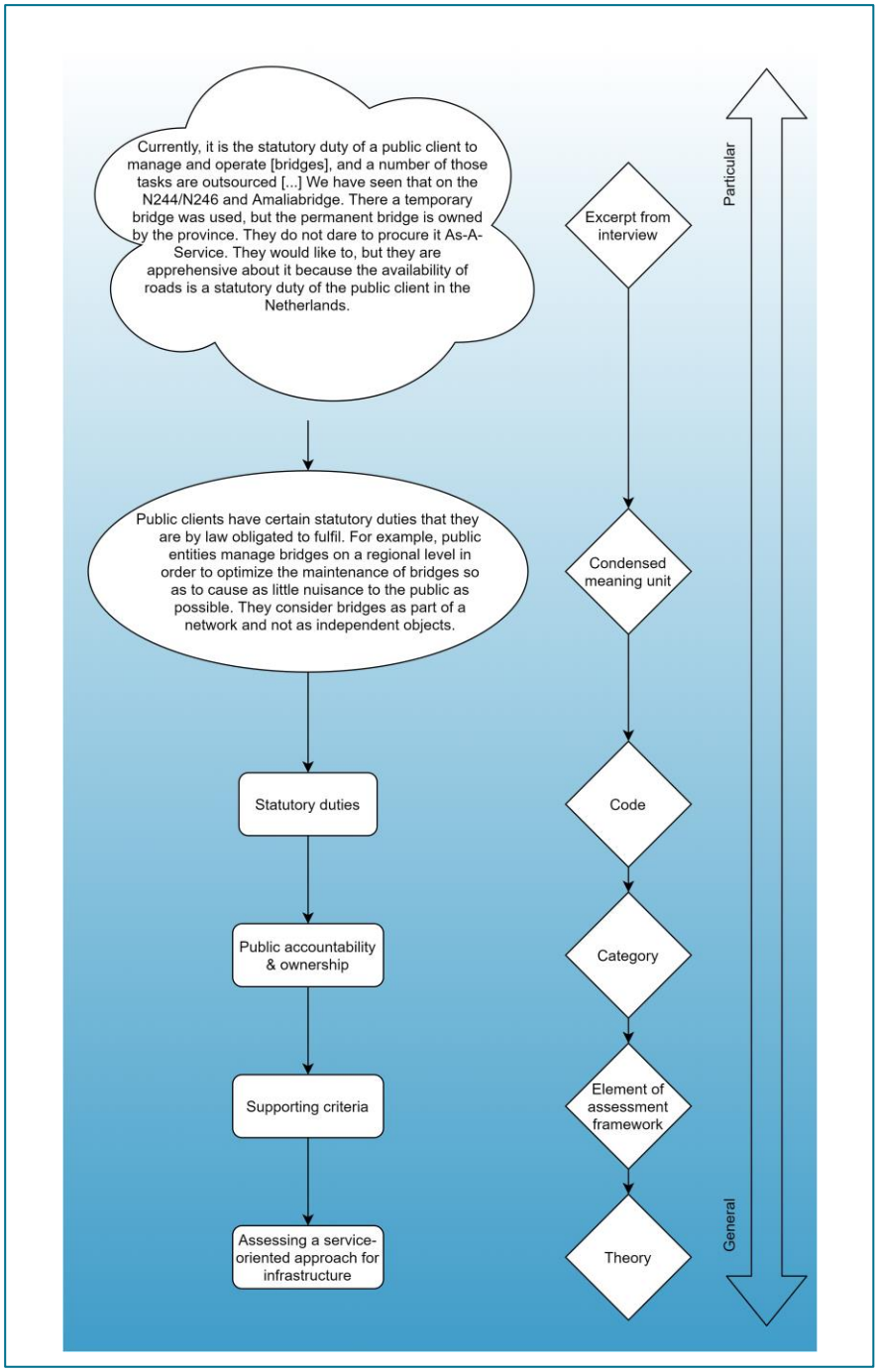


Figure 12 Analyzing process of interviews into theory

The assessment framework is divided into four parts, which are run through in chronological order to more effectively come to a judgment about the feasibility. If the prerequisites cannot be fulfilled, the process can be stopped, saving time and money by not further developing a service-oriented approach. The framework was iteratively designed, based on multiple designs and feedback session with both academic and company supervisors. Appendix II shows the iterative designs.

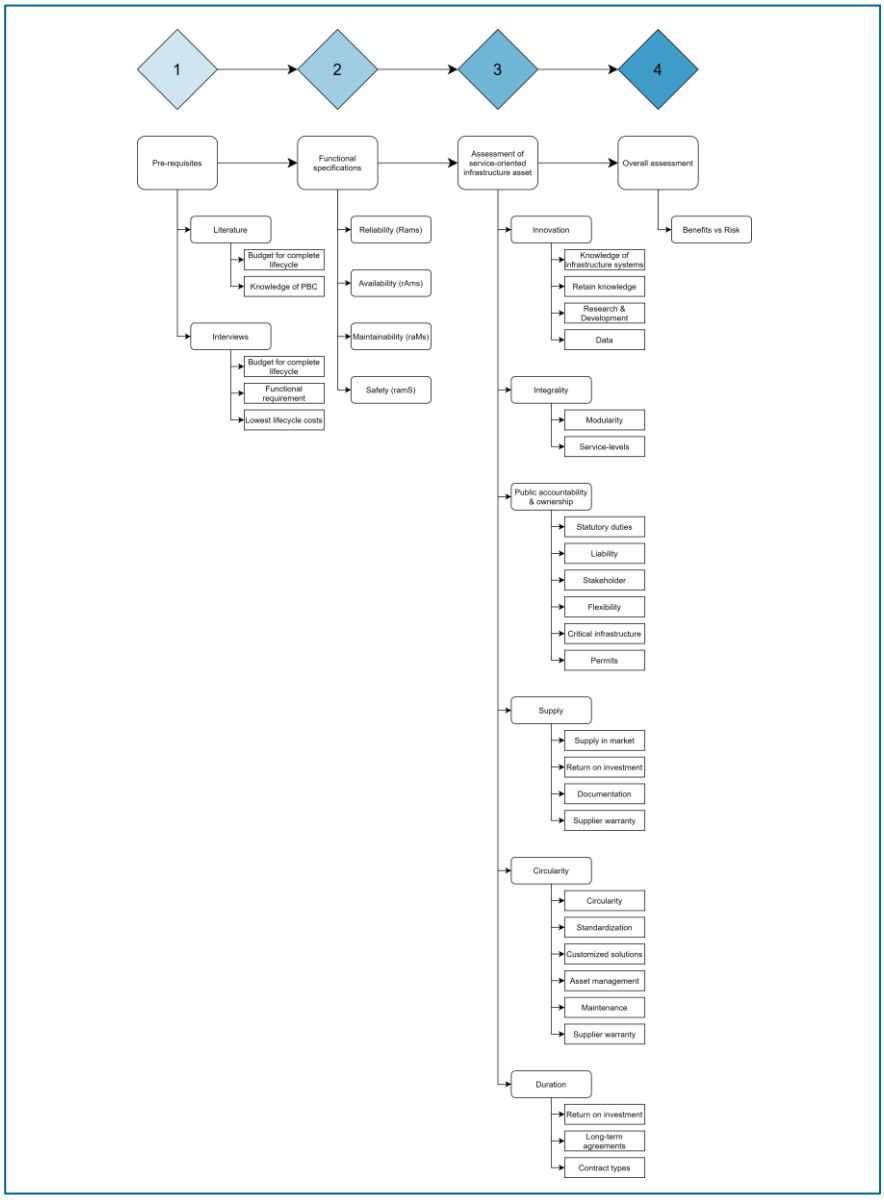


Figure 13 Steps, categories and codes of the assessment framework

4.4.1 Prerequisite assessment

Budget available for both design & construction and maintenance & operation:
The client has a budget for the available for the complete service life of an asset. A majority of projects are carried out on one budget for the realization and another one for the maintenance. If a public client needs to cut down on the budget, it often happens through the maintenance budget.

Ability to set functional requirements:
Clients have to be able to formulate their wishes in functional requirements. What is the function that an asset is supposed to perform? For example: provide a connection, pump water, or produce solar energy. Having some technical requirements will not render a service-oriented approach unfeasible, but functional requirements should provide the starting point.

The client wants to think in terms of total life-cycle costs:
An asset will be assessed based on the costs of its complete designed service-life. More expensive construction costs that offset larger maintenance costs would be preferred, rather than a cheaper asset that is more expensive to run and maintain. To make a proper assessment, also the end-of-life stage needs to be taken into account.

The client has knowledge of performance-based contracting:
Clients need to have experience with PBC. If they do not have know-how in-house, they need to get assistance from e.g. an engineering consultancy (Hartmann et al., 2014). Hartmann et al. (2014) also emphasize that buying performance is not the same as outsourcing, and the client needs to stay involved throughout the contract duration to maximize the potential by co-creating value with the supplier. With a requirement that is too abstract, the supplier can be given perverse incentives, or the goal of the client is not achieved. By specifying the performance in too much detail, the supplier does not have enough room to improve the service in the most efficient manner possible.

4.4.2 Main functional criteria assessment

A main functional criterion is set for the project. RAMS is used to set the performance level that the client wants to be fulfilled.

Reliability
Reliability relates to the probability that an asset will provide the service (=will work) when demanded. Smith (2013), showcased how efficient Rolls-Royce was at improving the reliability of aircraft engines by using predictive maintenance and constant data collection. Experts on moveable bridges and pumping stations also emphasized that suppliers are very good at predicting what part is causing a problem. If they have multiple assets of the same type installed, they will also use the data from an asset for the maintenance of all the other assets.

Availability
The availability means the time that an asset is available for use, i.e. not being maintained. The availability requirement especially for mobility infrastructure such as moveable bridges is often very close to 100 percent. Pumping infrastructure has more room for maintenance as long as daily pumping targets are met.

Maintainability
The maintainability implies the ease at which an asset can be maintained and it is calculated as the mean-time-to-repair for both planned and unplanned maintenance.

Safety
Safety generally implies the absence of human injury and loss of life. This requirement extends to both users, maintenance staff, and operators. The system is supposed to work as planned without causing harm. This requirement is the most difficult to transfer to a supplier as it is often a statutory duty of a public authority.

4.4.3 Supporting criteria assessment

Innovation

Innovation is the capability of an organization to improve the asset or service it is supplying and to develop new assets and types of service. It is the added value of combining an asset and service provider into one, who is then able to continuously improve all of the RAMS aspects based on data gathered during operation and maintenance.vHere the client will also need to decide on whether a service that improves over time is more important or the exact specifications that are determined at the start of a contract. In the first case, the supplier would have to present their chain of research and development and how a discovery during maintenance leads to an improved asset in the construction phase and vice versa.

Integrality

This aspect can also be translated to the scope, what assets will fall on the responsibility of the supplier to provide. Roughly, this can be divided into software, electrical-, mechanical- and civil parts. The more parts that are part of a system (the more possibility for integration), the more a supplier can optimize the system. However, by asking for a more integrated system it also requires more from a supplier, who in turn might need to subcontract parts of the system from other parties, leading to a loss of focus in developing the service.

Public accountability & ownership

What risks and responsibilities are the public clients allowed to transfer to a supplier, while still fulfilling its statutory duties. Huizing (2019) also mentioned the difficulty of letting a private party remain the owner of public infrastructure in the Netherlands. In case a private party remains the owner of an asset; what is the responsibility of a public authority in the event of a failure? The costs of a catastrophic even play heavily on this aspect. How do the improved efficiencies of the system weigh against the costs to a public authority and harm to the public in case of a failure of the system?

Based on the interviews, ownership is not the most important factor in fulfilling the requirements set by a client. Circular goals can also be reached through take-back or specific design specifications or norms that standardize certain parts. DBFM contracts have also turned out not to create innovation but rather improve on the workflow by the contractor and shortening the time between different steps in the construction process and keeping the project within budget. According to participants, a shift towards life-cycle costing and focusing on functionality and use matters more than ownership.

Supply

How many suppliers are there in the market that could potentially provide an asset through a service-oriented approach? Both how many suppliers are capable of providing certain assets as well as their willingness to provide added services play a role. For example, steel manufacturers of moveable bridges will be less inclined to provide any added services of its steel, as it works against their business model of keeping the steel plant as fully occupied in producing parts for 'just-in-time' delivery so that they can minimize logistics and storage costs. Pump manufacturers meanwhile are providing added services, such as maintenance, because it helps them improve their products and it supports their business model. What is the risk of a technological lock-in due to the choice of service supplier? If it is considered large, it would be beneficial for the client to remain the owner of the asset and specify what type of technology is supposed to be used (Hoogvorst et al., 2017).

Circularity

What role does circularity play for the client and how do they want to safeguard circularity? An integrated approach gives suppliers the incentive to make more robust parts to fulfill the main requirements (RAMS), but on the other hand, an asset may be over-dimensioned if the reliability aspect is much more important than the emphasis on circularity. This aspect is also closely related to the last aspect, duration. There is no simple way to determine what kind of circularity within infrastructure fits very well with a service-oriented approach. Ideally, materials could be reused without causing an environmental impact, however, the concrete and steel industry does not offer circular solutions (Dijksma & Kamp, 2016).

Duration

What is the duration of the contract? On one hand, suppliers should be able to earn back their investments, on the other hand, the contract duration should not be so long as to include an increasing amount of unaccounted risk due to changes in material costs, salaries, technology, and public policy to name a few. The duration of a contract should then be long enough for the supplier to earn back their investment in physical infrastructure, short enough for the parties involved to be able to plan until the end of the contract and ideally it would also reflect the service-life of the underlying infrastructure, or even motivate the supplier to extend the service life if it leads to a lower environmental impact and lower costs.

4.4.4 Overall assessment & financial feasibility

Based on the pre-requisite test, the main and supporting criteria, the client should make an overall assessment of the viability of a service-oriented approach. According to the participants, the decision to proceed will be a political one. The criteria do not have a scale because there are no criteria according to the experts that will automatically lead to a better result. After all, almost every situation is unique and requires placing the asset in a broader picture. The decision on viability will thus be based on the client's knowledge of the asset and performance-based contracting. Public clients have thought of the possibility of procuring service-oriented infrastructure in a few cases, but according to the participants they stranded because the risks were deemed higher than the benefits and it made them apprehensive to proceed.

4.5 Validation

The assessment framework model was validated by a contract manager for a water board in the Netherlands. For the prerequisites, the client's knowledge of performance-based contracting should be emphasized. According to the expert, clients steer projects on all four RAMS requirements. It also forms a good starting point for having clear requirements going forward with an assessment of the specific characteristics of a service-oriented approach. The contract manager was missing the financial consideration from the model. Because the financial is dependent on all the other requirements set by the client, the financial consideration was added to the overall assessment, where a rough financial estimation for the TCO will be made, which can be compared to a traditional procurement model for reference.

The participant did see the possibility of having a pumping station in ownership of the water board, but the pump itself would be provided as a service from a pump supplier. The transaction costs for removing or replacing a pump are small enough that this approach could be viable. To guarantee competition between suppliers and to not force a supplier to plan further than it is currently possible, the participant emphasized that the contract length should be no longer than 15 years at a time.

Based on the validation interview, the assessment framework was improved and the final version is displayed in Figure 14. The validation interview also confirmed that all the elements in the assessment framework are measurable (Table 5.2).

Table 4.7 Possibilities to assess an asset based on the framework

Criteria	Possible approach
Innovation	Let the supplier show how input from the maintenance team leads to an improvement of the product or part thereof on the production side. How are they communicating with each other, how often and how is this documented? The supplier should be able to demonstrate that their product is continuously and systematically being improved.
Integrality	Based on the specific asset, determine which parts are essential from an optimization point of view.
Public accountability & ownership	Assess whether or not the asset falls under the statutory duties of a public client.
Supply	List how many possible and realistic suppliers there are.
Circularity	Let suppliers show how materials would be recycled, or determine the percentage of re-used parts and materials that can be used.
Duration	Make an estimate of the return-on-investment time for the asset or the system if a large pre-investment is necessary.

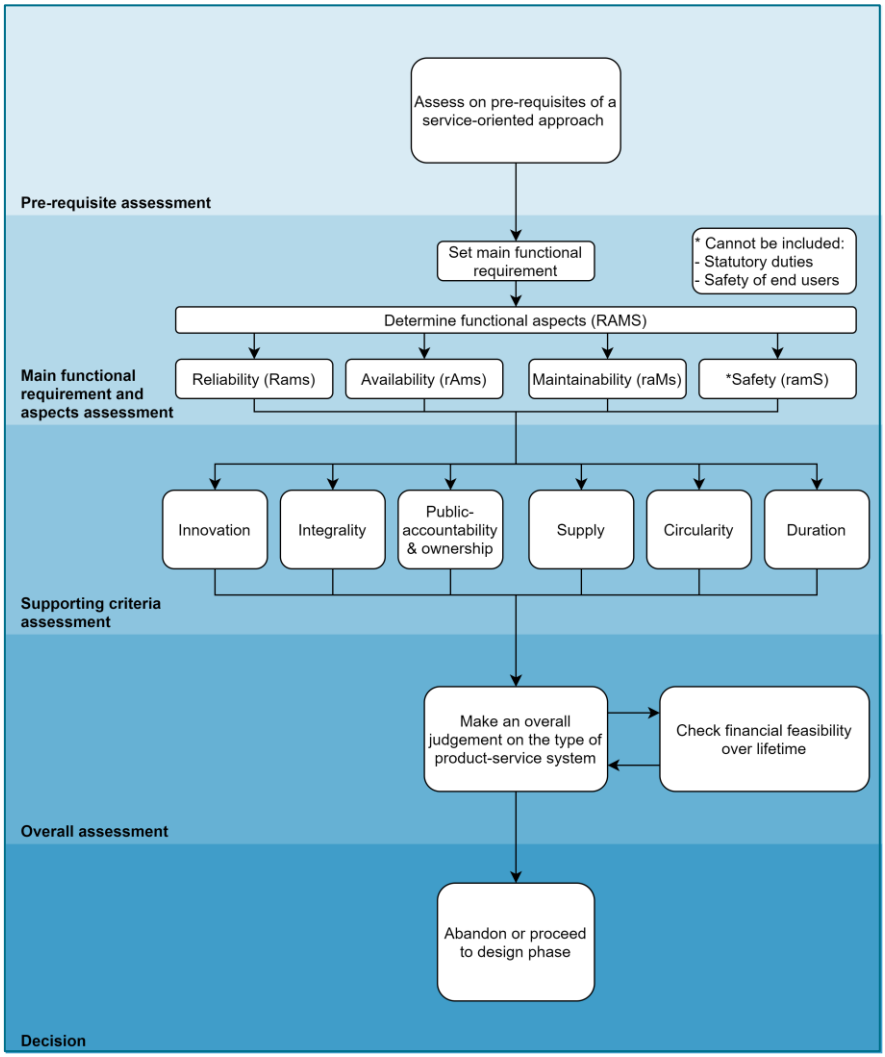


Figure 14 Assessment framework for a service-oriented approach

5

DISCUSSION

This chapter discusses the research findings and aims at addressing gaps in scientific literature and also validate and question findings in previous research. The results highlighted several aspects of a service-oriented approach that need to get more attention from public clients to make this type of service delivery possible. The findings can also be applied to other project delivery models. Planning and thinking in life-cycles of assets should become part of every infrastructure project, whether or not the maintenance is outsourced.

5.1 Characteristics of infrastructure enabling a service-oriented approach

From 4.2 it becomes clear that the theory of high capital costs, long asset durability, large involvement of public organizations, high systemness, and heavy regulation are indeed present in all three types of infrastructure that were examined in this study. For environmental impact, it depends on the specific type of impact and for competition intensity, it depends on what asset is assessed. For the seven characteristics discussed in 2.7, it can be concluded that they do not, except for asset durability, determine whether or not an infrastructure asset could be realized through a service-oriented approach. For example, it is not the involvement of public organizations as such, but their statutory duties and organizational form that in part determine whether or not a service-oriented approach could be feasible. None of the characteristics of the three types of infrastructure show service-oriented enabling qualities, where the participants would say "this can really benefit from a service-oriented approach". The types of infrastructure assets researched in this study also starkly different from the type of assets in traditional Product-Service System literature. The argument to not waste resources also does not have the same weight as for products for the consumer market, as public clients do extensive research before procuring construction projects or buying assets such as pumps.

5.2 Public organizations base their approach on statutory duties

It became clear through the interviews that the procurement approach chosen by public authorities is strongly influenced by their statutory duties and to a lesser extent on public policy. Especially in the Netherlands, the goals on a circular economy are policy goals, whereas the statutory duties are laid down in law. Therefore, public clients will first and foremost fulfill the requirements set by the statutory duties and within the solution-space explore whether or not a design could be more circular. The participants were doubtful of the willingness or possibilities to either transfer or circumvent these duties to make a service-oriented approach possible. The participants also emphasized the role of public clients as managers of a vast network of infrastructure objects, whereby the functioning of the network is the primary goal. In the long-term, however, public policy is a steering factor and a few participants saw the public policy as a better tool to achieve certain circularity goals, rather than directly engage in infrastructure unless strictly necessary. Huizing (2019) briefly explored the possibilities of having contractors own the infrastructure they provide by splitting ownership in economic- and legal ownership. However, the participants emphasized that public clients have an important duty in keeping infrastructure available and agreeing with stakeholders on a network level, which a single supplier of a PaaS solution would not be able to do.

5.3 A service-oriented approach forces a move towards TCO

Many elements of a service-oriented approach are already in use in the Dutch infrastructure sector today. The RAMS criteria, for example, is the norm for integrated contracts. Public clients are also making use of functional requirements and more and more realizing the benefits of planning infrastructure from a Total Cost of Ownership point of view. A service-oriented approach was seen as most beneficial to shift towards planning in terms of Total Cost of Ownership. The participants also reflected that infrastructure would likely be better maintained under a service-oriented approach, but it would come at a higher cost. Emphasized in every interview was the need for especially clients to think in terms of life-cycles rather than design & construct and then maintenance. Maintenance and design directly correlate with each other; decisions taken at the design stage have a sustained influence on asset throughout its lifecycle. Cheap solutions will likely create an added need for maintenance; sometimes still being the more affordable alternative, however, these should well-founded decisions based on life-cycle thinking and not keeping the initial construction costs low. Politically, however, opting for a more expensive solution that will show savings spread out over the next 50-100 years is not an easy thing to do. Most of the construction revenue earned by contractors in the Netherlands continues to this day to be through traditional contracts (without maintenance).

The results also show a discrepancy between different types of public authorities. Waterboards and public utility companies, such as water treatment plants are very well maintained. The pumps in pumping stations most often reach a service-life far beyond what it had been designed for due to good maintenance. However, technology has advanced far even in the pumping industry and modern-day pumps are themselves able to predict and order maintenance based on sensors. New pumps are also more efficient than old pumps, using less energy and a different energy source (electricity instead of diesel). The improvements based on technology then start to surpass the benefit of a really good maintenance scheme that extends the intended service life. That is why life-cycle thinking is so important. If a new pump would show lower use of energy over the next decade or two, earning back the difference between investment and lower energy costs, the investment should be made.

5.4 Codes not included in the assessment framework

As mentioned in Chapter 3, the aim of the assessment framework is to as efficiently as possible, determine the feasibility of going forward with a service-oriented approach to the design phase. This means the framework does not include all the codes that were developed from the interviews with infrastructure experts.

Alternative financing
Venture capitalism
Oversupply
Optimization
Public value
Robust design

These six codes that are not addressed by the assessment framework represent financially unquantifiable risks and values. For example, what is the risk of a venture capitalist firm taking over a supplier of infrastructure assets and stripping it of research and development or maintenance capabilities that results in a collapse of the structure? Optimization of assets and the risk of failure due to optimization is another difficult one to quantify. Public clients want optimized designs but they do not want the optimization to lead to unexpected risks. According to participants, public clients tend to choose for more robust designs to minimize risks even without a specific calculation; after all a failure of a pumping station and the resulting flooding, would lead to the public humiliation of the responsible public officials and the water board as an institution. Private companies on the other hand would more likely put the probability of failure in financial terms and take a calculated risk.

It is one thing to tell a market party "this bridge needs X hours of maintenance on XYZ, how much does it cost?" than to say "Figure out how much maintenance this bridge needs and decide how to execute it, I will pay you X amount".

5.5 Nuanced picture of the efficiency of private parties

When it comes to infrastructure in the Netherlands, private parties have the biggest opportunity to innovate because they also manufacture the parts that are used in the provision of a service, such as pumps and bridges. But the reality is more nuanced than that. Especially waterboards have chosen to retain a lot of skilled technical workforce and they have a lot of knowledge about pumps, pumping stations, and water management. They do not however have the workforce nor the equipment to undertake construction and so they contract a private party. The key here is collaboration, not simply outsourcing.

Rao (2015), found no conclusive of the benefits of outsourcing. Often when there was a perceived efficiency in an outsourced service, it was due to a better geographical location or other unrelated sets of factors. Private companies tend to focus on profitable markets, and the public side needs to provide services in locations and markets that are not as profitable leading to a lower perceived level of efficiency. Hartmann et al. (2014) also emphasized how important it is for public clients to stay involved and co-create together with a contractor. This was also brought up in the interviews in a situation where clients have extensive knowledge of the infrastructure in question (waterboards), but not the workforce or equipment for construction. Currently, they use the Bouwteam model to transfer this knowledge to a contractor, instead of contractors themselves undertaking an extensive round of interviews to gain the same level of knowledge that is present within the public organization.

The drive for a more service-oriented approach seems to in part be driven by private parties willingness to make decisions on infrastructure in part because they have gained more and more knowledge over the past decades as a result of public clients doing less and less of the engineering work. It is then too simply a statement that private parties are better or more efficient than public authorities; they simple have more engineering know-how in the current setting in the Dutch infrastructure sector.

5.6 Earlier studies

Huizing (2019) says that by "incorporating the (residual) value of materials in the financial system induce an economic incentive that is currently not applied. This gives opportunities to develop a project delivery method that can support the transition to a circular economy, which does not apply to the current integrated project delivery methods" (p. 51). The exploratory interview and the interview with participant 1 confirmed that material flows and recycling of the materials using currently available technology is possible. A combination of Bouwteam and D&C project delivery models was used to procure the replacement of a bridge with a reference design made by the same engineering consultancy where this study was also made. The NTA agreement mentioned in 4.3 helps to standardize interphases to be able to use parts from demounted bridges. There are thus also technical solutions appearing to achieve circular goals next to the financial business-model approaches. That is not to say they cannot be used together, however, the claim that the existing project delivery models are not able to support a transition towards a circular economy, is no longer valid. It depends on the wishes and requirements set by public clients.

The claim that "initiation of this new concept must be done by the client since the client is subjected to procurement legislation" (p. 53) is partly confirmed. However, in addition to the public client initiating service-oriented project delivery models, private parties in the construction market may invest heavily in developing service-oriented infrastructure assets and convincing public clients that large improvements can be made if, and only if, contractors are given more solution space.

On page 58 Huizing (2019) claims that "it is recommended to all stakeholders in infrastructure projects to start a transition towards service-oriented project delivery since this creates opportunities for incorporating aspects of a circular economy on a project level. When these aspects are applied, the circular economy becomes an integral part of the design at the start of the project." However, the outcome of this study points towards the

complete opposite. It is only recommended to start a transition towards a service-oriented approach when the infrastructure assets meet the criteria in the assessment framework. The framework does include barriers that may be overcome by restructuring organizations, but eliminating or easing statutory duties is not recommendable according to the participants. The citizens depend on public services and the public authorities take care to make sure these services are always available.

The research also validates the conclusion made by Geet et al. (2015) that great care needs to be taken when assessing whether or not a service-oriented approach is a right way forward. It also adds to the research by Huizing (2019), in terms of technical characteristics of different types of Dutch infrastructure assets.

5.7 Validity of results

The table 3.2 provides the framework for describing the steps taken throughout the research. The qualitative research methods, both the double diamond framework as well as the grounded theory methodology are elaborated in chapter 3. The study was facilitated by the engineering consultancy Witteveen+Bos, but the there were no predetermined results expected. As a member of the team on contract management and collaboration, experts were made available to support the research. The participants, as mentioned were initially chosen based on their expertise and experience with certain infrastructure. Because of so much information coming from a few participants, not all aspects can be explored during the interviews. The interview guide supported the process and digital tools were used to record all the interviews, which were later transcribed. Chapter 4 shows how the data was used and manipulated to design the assessment framework, in a way that the study could be replicated and the results would point in the same direction. The results showed saturation and while care was taken to begin every interview with an open mind and no pre-determined results, the interviews gave similar insights. The most challenging part of this study was the need to complete it completely digitally, due to requirements of social distancing during the coronavirus pandemic. Being in the same physical space with an interview participant is a different experience than interviewing participants via a videoconnection.

5.8 Limitations

The mixed methodology using grounded theory, results in certain limitations on the generalizability of the research findings. Because the theory is based on the input from specific participants, interviewing another group of participants could render completely different results. The assessment framework is based on the input of nine participants, from a narrow field of certain infrastructure. The assessment framework can not be applied to less critical infrastructure, where the importance of public authorities and public values is not as prevalent. Because the research looked specifically at public infrastructure in the Netherlands, the results can not as such be generalized for international infrastructure.

The assessment framework has also not been validated through a case-study on a real infrastructure asset and this could bring about new insights to add to the framework, especially if the input from participants could be quantitively quantified, for example, using the Analytic Hierarchy Process (AHP) to give weights to different categories based on preferences of public clients.

6

CONCLUSION

This chapter concludes the findings of the research and gives an answer to both the main- and sub research questions, as well as, discusses whether a service-oriented approach can be used to solve the problems presented in the introduction. Finally, recommendations both for the industry (clients) as well as for further research presented, to improve the value of infrastructure in the Netherlands and to advance the knowledge of product-service systems in the infrastructure sector.

6.1 What are the characteristics of a viable service-oriented approach of an infrastructure asset?

Based on scientific literature going back decades, more emphasis should be placed on the complete lifecycle of an asset. The first articles talked about servicizing, then a functional economy, and more recently product-service systems. From product-service systems, many sub-concepts were born such as product-as-a-service and Energy-Service companies. Performance-based contracts are often used to state how a service-provider will be compensated for proving a specific performance.

Most service-type concepts have their origins in the consumer or manufacturing industry and therefore they were not directly applicable to the infrastructure sector. However, by taking into account several key characteristics of the infrastructure sectors, the concept of product-service systems could be seen through the lens of infrastructure.

The performance that an asset in the infrastructure sector needs to deliver is far more complex than that in the consumer market and therefore, a lower environmental impact and circularity cannot by themselves be leading requirements. In other words, it is not as simple as just pumping water using less energy or making sure to recycle solar panels at the end of their service life. So much more is expected from and by public clients in the infrastructure sector.

6.2 How to assess the viability of a service-oriented approach of an infrastructure asset?

To assess the viability of a service-oriented approach, the double diamond method was used in combination with the grounded theory to create an assessment framework for a service-oriented approach. This framework is to be used at the feasibility phase of an infrastructure project, before moving on to the final design of a project. The first 'diamond' provides the discover and define phase in which experts of moveable bridges, pumping stations, and PV systems were interviewed to gather information on the specific characteristics of each type of infrastructure asset and how the concept of as-a-service could be applied to that specific asset. Much of the semi-structured interviews also focused on the capabilities, and the needs of public clients as they ultimately tender out the projects on the market.

The interviews were coded according to principle of grounded theory, using descriptive codes that are then categorized. These larger categories were then used to construct an assessment framework.

Several additional characteristics came up in these interviews, such as the role of statutory duties of public clients, ethical considerations, and the role of public clients in innovation. Based on the interviews a range of requirements of a service-oriented approach in the infrastructure sector was put into an assessment framework to be able to make a judgment in an orderly fashion. For some of the requirements, additional research was done to improve the elaboration and to make a stronger link to the service-oriented approach.

The framework was then validated on clearness, functionality, and content by a contract manager at a Dutch water board. This also represented the second diamond and the phases 'develop' and 'deliver'.

6.3 In what way does the assessment framework give insights into a service-oriented approach of a planned infrastructure asset?

The assessment framework has four steps. In the first step, certain prerequisites of a service-oriented approach are discussed to assess mostly whether the organization itself is capable of procuring a 'service'. Then the client has to set functional requirements on the front-end, which then are held against some key characteristics of a service-oriented approach in the third step. The functional requirements force the client to think in terms of what kind of performance is needed.

It became clear that there is no one wrong or right way of providing infrastructure assets 'as-a-service' and therefore the criteria aim at providing the reader with a qualitative explanation of the considerations that need to be done to be able to determine the feasibility of a service-oriented approach. In other words, as a client, these six criteria need an assessment to be able to make a judgment. Which aspect is more important than the other, and what will lead to the ultimate solution is impossible to say at this moment without empirical evidence of real-life examples (which do not yet exist).

6.4 What are the implications of a service-oriented approach for Dutch infrastructure assets, currently managed by pubic organizations?

In the introduction, three reasons for a service-oriented approach were mentioned. The need to shift towards a circular economy, the renewal and renovation of infrastructure in the Netherlands at a scale that cannot be solved by simply replacing assets with new ones and the ever-increasing complexity and value expectation of infrastructure. In theory, these problems can be solved through a service-oriented approach, but it is not the only way forward. For circularity, to be able to recycle materials on a high level, at least some form of technical requirements are needed for assets that outlive their initial service contracts. The Dutch infrastructure sector should be 100% circular within ten years, but with assets, such as the civil structure of bridges, having a designed service life of 100 years, it is very difficult to say whether or not a service-oriented approach leads to a more circular infrastructure sector, compared to an alternative approach. The combination of product and service should lead to a situation where they are both improving each other. So once the asset is disassembled and recycled in one way or another after 100 years, a judgment could be made on whether or not setting functional requirements has lead to the supplier coming up with a way to fully reuse or recycle the asset. To make that sort of judgment is not feasible at the moment and public clients of PV systems are currently looking at a take-back scheme for solar panels with a service life of 25 years.

A service-oriented approach also does not necessarily solve the infrastructure renewal deficit because if a private party takes over the maintenance and is paid based on the functional requirement, they will likely maintain the road better than a public party who is trying to only cover the most necessary maintenance with a budget that is too small to cover all maintenance. What it does do is force public clients to think in terms of lifecycles to prevent them from constructing assets, which they cannot maintain, and to have the best design possible from a life cycle perspective, rather than low construction costs.

Whether or not it can solve the increasing complexity of infrastructure remains to be seen but it seems promising for solutions where high technological know-how and capability are necessary. It can also lead to some type of infrastructure being more used because private parties have more incentives to fully utilize their assets. A service provider can for example use parts from a retired pump of one client for that of another, while public authorities would always need to purchase a new pump.

To answer the main research question *'Under what conditions is a service-oriented approach viable for Dutch infrastructure assets?'*, the service-oriented approach could be further worked out in the design phase when the public organization meets the pre-requisite criteria set in the framework, they can define their main requirements into functional ones (RAMS) and they have assessed the asset or project on all six supporting criteria. If the public client can formulate this into a performance-based remuneration scheme for a supplier and the approach seems to be financially promising, it can be furthered worked out.

When a client is thinking in terms of lifecycle costs, continuous improvement through research and development leading to innovations, and manageable contract durations, a service-oriented approach has the potential to create more value for the client than keeping D&C and O&M separated.

Some pilots are ongoing, but the attitude of public clients towards a service-oriented approach is very reserved and is going forward in very small steps according to the participants. This can also be seen in the distribution of construction contracts, whereby a large majority consists of only the design and construction phase.

6.5 Recommendations

6.5.1 For clients

It cannot be emphasized enough that a move towards life-cycle costing is critical whether or not accompanied by a performance-based contract. In the future, tough choices will have to be made over what infrastructure will be maintained and what will be removed and it would be helpful if the problem is not made worse by adding even more infrastructure that has an uncertain maintenance bill attached to it.

The service-oriented approach, however, gives many opportunities to make use of the technical progress that has taken place in especially electrical installations and machinery types of assets such as engines and pumps. Public clients tend to lag in this development because the added benefit can be quite small for the organization; it can create added uncertainty, or the client could be bound by some other contracts or policy. This applies less to the private supplier, where technological innovations can quickly be utilized in-house and on a greater scale if it concerns the core knowledge of a company.

For public clients, rather than focus on amassing as much knowledge about the newest technological innovations, they should improve on their ability to procure based on performance and look over the whole lifecycle. But remembering that outsourcing should not become a goal by itself; there is no conclusive evidence of the added benefit of outsourcing.

In cases where an asset and a public client fulfils the requirements and criteria presented in the assessment framework, they should consider using a service-oriented approach in order to reap the benefits of especially the research and development cycle of a supplier. As technology is advancing in a direction where data is more important than ever for improving assets, if supplier can show hoe the service will improve over time, the approach should become a viable option.

Engineering consultancies, such as Witteveen+Bos can use their knowledge in systems engineering to break down e.g. the research and development cycle of suppliers to see whether or not it fulfills the needs and requirements of the public client in question.

6.5.2 For further research

As many infrastructure-related topics, also this research centers around the technical and financial considerations. However, throughout the interviews, ethical considerations were also mentioned. How far should a public client go in transferring risk and responsibility to a private party? Disasters around the world, which often make headlines, like the bridge disaster in Genoa, showcase how outsourcing has taken a step in the wrong direction with disastrous outcomes.

For the topic to advance, it would be beneficial to be able to get empirical data from real-life projects. When that happens, many more new insights and possibilities for research will come about.
Since this research centered around the feasibility phase, the next natural step would be to work towards the design and tender phase. What kind of tender- and project delivery models could be useful for working out the right incentives for both parties involved?

Another topic that was often mentioned was how changes should be implemented into contracts. The lesson in the industry is not to break open contracts because it comes with huge legal- and financial ramifications. However, for the service-oriented approach to become more widely viable, some type of mechanism for adjusting the contract should be included according to several participants.

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Appendices

I CONDENSED MEANING UNITS FROM INTERVIEWS

The condensed meaning units from the 8 interviews are displayed below (Discover phase).

1	Moveable bridges	1 Bridges are designed with the following service-life expectations: [2] • Civil: 100 years • Mechanical: 50 years • Electrical: 15-20 years • Software: 5 years 2 A rough estimation of ratio capital costs versus maintenance costs over the service life of a bridge is 1:1. [1] 3 The operational responsibilities would have to be well defined in an As-A-Service approach as the operation of a moveable bridge can be split into the supply of energy and operating the bridge. [Statutory duties] 4 Results have shown that investments in the construction phase do reduce the need for maintenance in later phases. [1, Life-cycle costing] 5 The most important regulation specifically applying to moveable bridges is the Machinery Directive of the European Parliament and the Council. It not only sets technical standards but also organizational ones that specify who might operate a bridge, the organization, and safety in general. As a moveable piece of infrastructure, the whole bridge is considered a machine in the eyes of the directive. [6] 6 A barrier for As-A-Service is that different phases in the life of an asset are currently led by different departments within the public organizations. [6] 7 There is an ongoing shift from thinking about a structure to thinking about specific performance. The RAMS (Reliability-Availability-Maintainability-Safety) principle is getting more attention. Public clients are starting to realize that significant advances can be made by considering the total cost of ownership (TCO). [Functional specifications, RAMS, TCO] 8 Design choices that have the biggest impact on availability should get more attention in the design phase (e.g. electrical connections and buttons); not the parts that cost the most (civil structure). [RAMS] 9 The biggest advancement on moveable bridges can be made by improving the availability. Simultaneously, procuring a service instead of a physical object comes at a much higher risk for the client. If the supplier goes bankrupt, the service (the availability of a bridge) is no longer delivered. The consequences of the non-availability could wipe out all the improvements due to optimization. [Risk, 5] 10 The worst-case-scenario is however that a user of the bridge dies. This has happened a few times recently in Zaandam. [Risk, Liability, 5, 6] 11 Public clients have certain statutory duties that they are by law obligated to fulfill. For example, public entities manage bridges on a regional level in order to optimize the maintenance of bridges so as to cause an as little nuisance to the public as possible. They consider bridges as part of a network and not as independent objects. [5, 6, Statutory duties] 12 As-A-Service gives the opportunity to think more cleverly about resources and it has been shown to work on a temporary basis, for example, during the replacement of an existing bridge, by renting a temporary bridge. [Circularity] 13 Budgets for bridges are projects-specific and an As-A-Service would have to fit into this model, or the market would have to make a significant pre-investment, without certainty on the return on their investment. [Supply in market, 5, Return on investment] 14 In the preparatory phases of a project, a significant number of stakeholders are involved. Agreements that are made with the stakeholders, become part of the project and need to be included in contracts. [4, 5, Stakeholders] 15 The revised Revision and Planning Act requires clients and contractors to seek the participation of stakeholders in certain cases. This will surely complicate the opportunities presented by an as-a-service approach. [4, 6] 16 There is a gap in knowledge on both the technical side as well as the procurement side at public clients. To be able to procure infrastructure-as-a-service, it is important to also have knowledge about the system in question. The ones having to make decisions no longer have the know-how or ability to critically assess advice. [4, 5, Knowledge of infrastructure systems] 17 It is difficult for public clients to make long-term service agreements because they often do not have the mandate or courage to enter into agreements reaching past election cycles. Long-term agreements also set the budget for the coming years and reduce the flexibility of public clients to allocate the budget to where they see fit. All the money not spent on maintenance, even if deemed necessary, is money saved. [5, Long-term agreements] 18 The current NTA-agreement on moveable bridges is strictly speaking not a modular solution but it sets certain standards on the interphases between parts of a bridge. [Modularity, Standardization] 19 The efficiency of systems can be increased when using standard parts of which the suppliers are able to learn what parts wear out and why. [2, 7] 20 It is difficult for engineers who have learned to always design fit-for-purpose to transition into thinking in modules, which often are ideal for a specific purpose or location. [Modularity] 21 On a provincial basis (a network of bridges), designing bridges through the NTA-standard can give significant economic and environmental benefits, even if just one bridge, or parts thereof, is reused

			during its designed service life. It, therefore, makes sense on a network level to design all bridges in a modular fashion, because it is difficult to predict exactly which bridge eventually is reused. [5, Circularity]
		22	Energy neutrality on a recent bridge project was only possible by moving the operations of opening and closing the bridge to a central location. [5]
2	Moveable bridges	1	For the durability of steel bridges, the number of heavy axial loads on the bridge is decisive. Data on traffic needs to be connected to the service supply. [2]
		2	A company supplying temporary bridges sees the market as a service-levels (e.g. 1 km of "bridge", deployable within a week). [Service-levels]
		3	The market for bridges-as-a-service is a niche market; public clients tend to choose customized solutions and ownership for long-term solutions. [5, Customized solutions]
		4	The competitive advantage of a modular bridge-as-a-service supplier in comparison to a traditional contractor with a traditional design is that a bridge can be quickly deployed (as quickly as one day). [Flexibility]
		5	Asset management of a bridge-as-a-service is very important in order to know which part has been where and to make sure that parts used are in working condition. [2, Asset management]
		6	The company that was interviewed has built a stock of 25 000 tons of bridge parts over the past 50 years. It will take some time to get up to such a scale and have a designated engineering department for in-house research and development. [7, Supply in the market]
		7	It does not make sense for public clients to rent a bridge indefinitely in the current market, where the company is able to earn its investment back within three years. [Return on investment]
		8	A barrier to circularity is that both public and private clients often require new parts in order to be sure that they fulfill the requirements. Increased national building-norms also create barriers, as a part built according to old standards might not fulfill the new standards. There should come EU-wide standards for reusing parts of public infrastructure. [5, 6, Circularity]
		9	Public clients should accept more modularity in public infrastructure in order to allow for more circular solutions. This will lead to the standardization of designs to some degree. [Modularity, Standardization]
3	PV systems & moveable bridges	1	As-A-Service is interesting from a maintenance- and circularity point of view. Mainly for control and moving parts. [2, Maintenance, Circularity]
		2	The industry is currently looking at As-A-Service for civil parts; despite electrical parts having a shorter service-life and higher technology, they are not yet part of the discussion. [2]
		3	Critical infrastructure in the Netherlands should be controlled and available for everyone, which is a barrier for As-A-Service. [5, Critical infrastructure]
		4	As-A-Service also gives public clients more financing choices, but under no circumstances should infrastructure be financed by venture capital. The bridge disaster in Genova has shown what the consequences of an unbalanced financial structure can lead to. [Alternative financing, Venture capital]
		5	Functional requirements should form the basis for an As-A-Service procurement. [Functional requirements]
		6	There is a transition of knowledge from public entities to the market parties, within the infrastructure industry. The market needs to agree where the knowledge should be in order to make sure it stays on a high level. [Retain knowledge]
		7	Public entities should retain some knowledge and control over critical infrastructure. From a maintenance and operations point of view, this could mean that public entities are able to solve the most simple and straightforward issues and the supplier would have responsibility for more complex problems with the incentive to reduce the number of problems to a minimum. [5]
		8	Public authorities should also think about how to keep the Dutch knowledge-based economy competitive. Outsourcing based on price only will lead to knowledge flowing abroad and a diminished competitive position of the Netherlands. Public authorities have the possibility and responsibility to push for innovations through procurement. From the perspective of the public, the cheapest solution is not the most profitable. [5, Research and development]
4	PV systems	1	PV systems are very low on maintenance. Once installed, the panels only have to be cleaned once in a while and the transformers have to be replaced after 10-15 years. [1, 2]
		2	For PV systems connected to critical infrastructures, such as to power a water treatment plant, the technical detailing on installation and construction is very high. Very few parties, mostly traditional contractors, are used to and able to provide sufficient documentation to fulfill the requirements set by public authorities responsible for critical infrastructure. [5, 6, Critical infrastructure, Documentation]
		3	When connecting PV systems to critical infrastructure, it is important that emergency power systems and other vital elements of infrastructure are not disturbed by the PV system. [4, 6, Critical Infrastructure]

		4	Public clients steer on take-back schemes for solar panels at the end of their designed service life. There is an organization (Stichting ZRN) that is currently developing the recycling of solar panels. [3, Circularity]
		5	Land use is something that needs to be taken into account when realizing PV systems. Future needs of land need to be explored before placing solar panels so that they do not have to be removed during their designed service life. [2, 3, 5]
5	PV systems	1	PV systems are based on high capital expenditure and a full return of the investment within 15 years, including a subsidy. [1, Return on investment]
		2	The technically designed service-life is 25 years with inverters replaced after 10-15 years. What happens to PV systems after 15-25 years is still unknown. The system could remain in place, it could be sold to another party or removed. [2, Circularity]
		3	Producers of panels often guarantee a certain yield throughout the service-life of panels. The yield per panel decreases over time but it usually does not suddenly fail. [2, Supplier warranty]
		4	2/3 of total capital expenditure for the core PV system is for panels. Other parts include inverters, cables, and structures to keep the panels in place. [1]
		5	The placement of the system is crucial for how easily a project can be realized. An environmental permit might be needed. Public clients may also ask parties to apply for their own permit (Rijkswaterstaat) or documentation fulfilling the NEN-1010 norm. Placement on a roof is the most simple in terms of permits. That is also the preferred placement at the moment. [3, 5, 6, Documentation, Permits]
		6	Municipalities, but recently also the government, have published their own guidelines for how PV projects can be realized (NL: zonne-ladder). [5, 6]
		7	The guidelines do not take As-A-Service into account. They are aimed at more traditional contracts. [5, 6]
		8	Public policy is the strongest tool that municipalities and regional authorities have to steer how PV systems are realized. They have more influence via policy than via their own solar projects. They are more in a facilitating role when it comes to PV systems. [5]
		9	Many parts of PV systems have been standardized, for example, all solar panels are of the same size. [Modularity, Standardization]
		10	Environmental impacts of panels are [3]: • The area they take up, if not place on existing infrastructure. • Emission from production and shipping. • Emissions from the construction phase.
		11	By building nature-inclusive, the placing of panels can create a surplus for the environment by creating a shadow where certain species can survive. By placing panels on agricultural land, and thus creating an income for a farmer, the soil gets to rest and there will be a reduced amount of phosphates flowing into the surrounding water. [3]
		12	Some parties in the Netherlands are already able to recycle materials from solar panels. [3, Circularity]
		13	In the coming years, the oversupply of renewable electricity will become a problem. As a result, systems need to be switched off or there needs to come to a solution to store the additional energy. If projects are financed by market prices this will present a risk for the suppliers as the price decreases or even becomes negative in some circumstances during peak production. An integral solution needs to be worked out where the electricity network is made more robust and supply meets demand. [4, 7, Oversupply]
6	Pumping stations	1	Pumping stations are designed with the following service-life expectations: [2] • Civil: 100 years • Mechanical: 25-40 years • Electrical: 15 years • Process automation: 5-10 years
		2	An increase in the pumping height and capacity can be due to three reasons. Climate change (e.g. change in rainfall), sea-level rise, and subsidence. They are all physical phenomenon and easy to predict. Changes to the water level are made on average once every 25 years (NL: peilbesluit). [6]
		3	A pump can be changed for a few reasons: [2] • It has reached the end of its service life and there are no longer spare parts available. [2] • A new type of pump would be so much more energy-efficient that it would make sense to switch pumps.
		4	Water boards are liable for damages due to flooding and they have a statutory duty of water management in the Netherlands. [5, 6, Liability]
		5	Any As-A-Service would have to fit within the legal framework of water management. [Statutory duties]
		6	A great degree of systemness exists within pumping stations. The electrical parts and process automation are also often part of a wider network in the area. It would be difficult to have one pumping station delivered As-A-Service and another managed by a water board. [4]

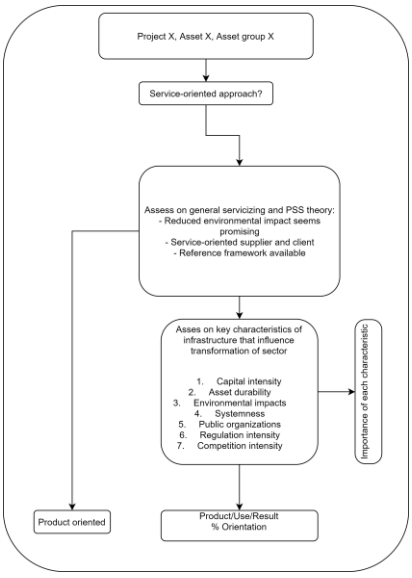
		7	The As-A-Service would have to improve on two levels; from an investment point of view the rate of depreciation needs to decrease and from a business operation point of view, the cost and need for maintenance need to reduce. [Optimization]
		8	Currently, the water boards choose more expensive solutions, which require only little maintenance. The aim is to need to do as little unexpected maintenance as possible. [2, 5, Robust design]
		9	The biggest question around As-A-Service for water boards is what happens if a service is not delivered or it is poorly delivered. The damage and the liability claims that follow can be ten times any profit earned through optimization through an As-A-Service. [5, 6, Liability, Risk]
		10	The degree of modularity is quite small for pumping stations. [Modularity] • The foundation is always unique for each station. • Pumping height and capacity varies for each location. • Some standardization can be possible, e.g. the building envelope of a pumping station has a standard design in many water boards.
7	Pumping stations	1	As-A-Service would require more from the supplier than is customary today; especially difficult is to make them look ahead up to 100 years, with 3 replacement cycles of the pumps and 4 cycles for the electric installations, over the service life of the civil structure. [1, Contract duration, TCO]
		2	As-A-Service would force the supplier to take everything into account in life-cycle analysis and make a choice between a more robust or cheaper design. [2]
		3	Water boards generally choose more robust materials without a specific life-cycle analysis calculation. [5, Liability]
		4	Water boards set very specific technical specifications on pumps and other installations. It requires a lot of documentation from a supplier. Suppliers have to be able to prove through documentation and factory tests that the designed service-life can be reached. The longer the designed service-life is, the more detailed the specifications usually are. [2]
		5	A supplier would have to consider both maintenance- and amortization costs in its supply of a service. [1, 2]
		6	How do you prevent a venture capitalist from taking over a supplier, which has made a long-lasting agreement with a public client? Venture capitalism does not work with infrastructure because it is supposed to serve a whole society. [5, 7, Public value, Venture capitalism]
		7	For the water board, ideally, as long as a supplier can show that the RAMS specifications are fulfilled it should not have to matter what specific parts are used. [RAMS, Circularity]
		8	How strict the RAMS specifications are, depends on the water board and their clients. Some water boards have e.g. higher technology greenhouse agriculture in their area, which means that the damage in case of a failure is also larger than in areas with more traditional field agriculture [5, 6, RAMS, Risk].
		9	Pumps traditionally do not fail, whereas, for example, water level meters do. However, there is not enough data to know when and how these smaller but vital components behave. Data collection has only recently started. [5, Risk, Data]
		10	Preserving knowledge is important. If water boards outsource the maintenance to an outside party, how is the knowledge preserved? Maintenance personnel of water boards often have decades of experience with maintaining pumping stations. How are suppliers able to retain or employ people with such knowledge? [Retain knowledge]
		11	Pumping stations are central to the duties of water boards and outsourcing such a central task that is central to their image, would be apprehensive. [5, 6]
		12	The regulation relating to construction is stable, whereas the regulation on water safety is changing more rapidly, indirectly leading to higher requirements on the infrastructure. [6]
		13	Modularity plays a role in the design phase of pumping stations. Anticipated future increase in pumping capacity should be prepared during the construction of the civil structure. Space should be built for anticipated future needs so that more capacity can be added later. [2, Modularity, Circularity]
		14	Water boards try to reduce their environmental impacts, but there is no alternative for pumping stations. [5, 6]
8	Pumping stations	1	A high degree of systemness is embedded in the water management depending on the water board. [4]
		2	Certain pumping stations (e.g. Gemaal Buma & Vissering) form a dual system. One is used in summertime (electrified) and the other is used more in the winter (heating for the nearby industry). [4, Stakeholders]
		3	A big unresolved problem is whether the market agrees on certain standardized parts that anyone can supple or that every supplier only produces parts developed in-house. In the long-term, the market would likely profit (as did the ICT-industry), but it might be difficult to accept in the short term. [7, Standardization]
		4	Agreements should be made beforehand on what happens in case the client wants to take over the infrastructure. E.g. agreements on how you would agree on the value of the system. This could lower the threshold for public clients to use As-A-Service as they could take over the infrastructure if they would be unhappy with the delivered performance. [5, Valuation]

		5 How do you guarantee that a party still exists after 30 years? [2, 7] 6 Some similarities with the current DBFM models [Contract types]

II ASSESSMENT FRAMEWORK ITERATION

APPENDIX:

The iterations of the assessment framwork are displayed below.



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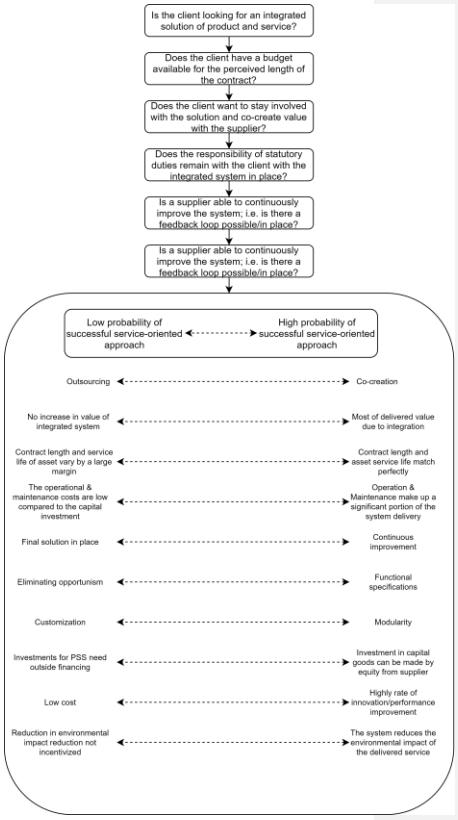

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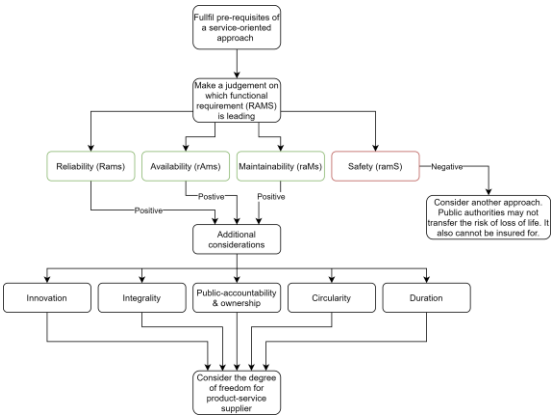

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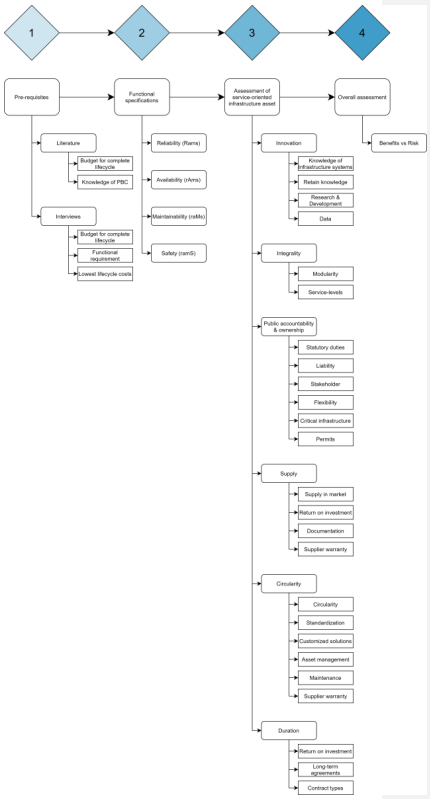


Version 4.0

III THE INTERVIEW PROTOCOL

Interview protocol

Goedemorgen (dag), mijn naam is Matias Biese. Ik ben student van de Master Construction Management & Engineering in Delft en ik studeer af bij Witteveen+Bos in de groep contractmanagement en ketensamenwerking (met standplaats Breda). Allereerst bedankt voor het vrijmaken van uw tijd om deel te nemen aan mijn afstudeeronderzoek. Kunt u mij goed zien en verstaan (technische check). Voordat we beginnen zou ik u willen vragen of ik het interview mag opnemen?

We gaan de asset/project X bespreken, kunt u mij kort toelichten wat uw rol daarbij is/was en wat uw rol binnen W+B is en hoe ervaren u bent in vergelijkbare projecten?

Doel van dit onderzoek:

Het doel van het afstudeeronderzoek is om inzicht te krijgen in hoe men zou kunnen beoordelen of assets of infrastructuurprojecten mogelijk geschikt zou zijn voor een As-A-Service aanpak. Ik gebruik de resultaten van de interviews om een afwegingskader te ontwerpen dat gebruikt kan worden bij de verkenningsfase om te beoordelen hoe kansrijk een as-a-service aanpak is voor een asset of project.

Het achterliggende idee van as-a-service is dat opdrachtgevers als het ware een dienst kopen i.p.v. een product; de eigenaarschap van de fysieke asset blijft dus in handen van de dienstverlener of opdrachtnemer. Verder is de ‘product’ niet te splitsen van de dienst die geleverd worden. Deze aanpak kan meerdere achterliggende doelen hebben, bijvoorbeeld een grotere gebruikerswaarde tegen lagere kosten door alleen te betalen voor vooraf afgesproken resultaten, of een verlaging van de impact op het milieu door een circulaire business model mogelijk te maken. Hoe meer men gaat richting een result-oriented oplossing, hoe groter de oplossingsruimte is voor de opdrachtnemer en hoe meer de prestatie ten opzichte van een traditionele aanpak verbeterd kan worden. Tegelijkertijd nemen de risico’s toe dat de opdrachtnemer niet de beoogde resultaten kan behalen of dat de opdrachtgever niet krijgt wat zij voor ogen had.

U bent misschien bekend met begrippen zoals print-as-a-service en wash-as-a-service (infrographic). Die businessmodellen zijn al toegepast in de B2B en consumentmarkt. Deze sectoren verschillen echter van de infrastructuursector en daarom is het niet mogelijk om de uitkomsten 1-op-1 te vertalen. Aan de hand van zeven specifieke kenmerken voor de infrastructuur sector ga ik samen met u verkennen wat de vertaling zou betekenen voor infrastructuur assets. Ik zal deze kenmerken kort toelichten en daarna vraag ik u om te vertellen wat dit betekent specifiek voor het asset X en daarna breder voor bruggen/gemalen/zonneparken.

Doel van gesprek

Het doel van dit gesprek is om aan de hand van zeven kenmerken van de infrastructuur sector, verkennen welke afwegingen gedaan moeten worden om een beslissing te kunnen maken over of het wel of niet kansrijk zou zijn om een as-a-service verder uit te werken in de planuitwerkingsfase.

De kenmerken die aan bod komen zijn:

1. Asset durability
2. Capital intensity
3. Regulation intensity
4. Systemness
5. Public organisations
6. Competition intensity
7. Negative environmental impact

Eerst wordt gekeken naar de specifieke asset en daarna wordt gekeken of die bevindingen ook voor de bredere assetgroep gelden (specifiek brug naar bruggen in het algemeen).

Zeven kenmerken van transformatie in de infra sector	Toelichting	Vragen Per kenmerk, *'wat is het gevolg voor een as-a-service aanpak?'*. Als de interviewde veel te zeggen heeft over een specifiek kenmerk, dan kunnen de onderliggende vragen gebruikt worden om dieper inzicht te krijgen.
Asset durability	Infrastructuur assets hebben een veel langere levensduur in vergelijking met producten waar het as-a-service concept al toegepast wordt (witgoed, auto's, printers, kleding). Daardoor is het vernieuwingstempo (en productverbetering door iteratiecycli) ook veel lager dan in andere sectoren.	1. Wat is de verwachte/ontworpen levensduur van de asset? 2. Is de levensduur van de asset bepaald op technische eigenschappen? 3. Hoe goed is de functionele en de economische levensduur te voorspellen t.o.v. de technische levensduur? 4. Hebben onderdelen van de asset sterk verschillende levensduren? What is the planned service life of the asset? Is the lifespan of the asset determined on technical specifications? How well can the functional lifespan of an asset be forecasted in comparison to the technical lifespan? Do the lifespans of parts of the asset vary widely from each other?
Capital intensity	Met kapitaalintensiteit wordt hier bedoeld dat de kapitaalkosten een aanzienlijk deel van de levensduurkosten uitmaken (30-60+%).	1. Wat is de verhouding van kapitaalkosten t.o.v. van operationele- en onderhoudskosten gedurende de hele levensduur van de asset. What is the ratio capital costs versus operating and maintenance costs during the lifespan of the asset?
Regulation intensity	Regulation intensity (regelintensiteit) betekent alle extra regels en normen bovenop algemene, niet-sectorspecifieke, aanbestedingsregels.	1. Welke normen en regels moeten in acht worden genomen bij deze asset en assetgroep? 2. Zijn deze regels technische (bijv. moet 5m3 water/uur kunnen pompen), functionele (bijv. het waterpeil moet niet te hoog worden) of organisatorische van aard (bijv. de

Commented [AS-B1]: Ik gebruik de term service life in plaats van lifespan.
Nog aandacht voor economische service life?

	Wordt de prijsvorming ook bepaald door de overheid - veel gerugereeld vanuit wet- en regegeving.	operationele taken moeten bij een waterschap uitgevoerd worden)? What specific regulation relates to this asset and asset class? Is the regulation technical, functional or organizational?
Systemness	Een hoge mate van systemness betekent dat als een onderdeel wordt aangepast, veel andere onderdelen ook aangepast moeten worden. Dit kan zowel een kans als een uitdaging zijn. Assets met kritieke functies hebben een hoge mate van systemness (zoals hoogwaterbescherming).	1. Hoe verhoudt zich de asset in relatie tot het netwerk dat er een onderdeel van is? 2. Wat zijn de mogelijkheden voor verschillende aannemers (onderaannemers) een PaaS aan te bieden binnen een systeem? (Verantwoordelijkheden) 3. Is er een mogelijk om functionele specificaties te stellen? (Is er ruimte voor verschillende oplossingen?) 4. Wat zou de gevolgen zijn als de asset wordt weggehaald aan het eind van de levensduur? (Blijft het netwerk intact en is het technisch mogelijk om het modulair te ontwerpen?) 5. Kan een asset aanbesteed worden op alleen functionele eisen zonder dat het systeem in gevaar komt? How do these assets relate to the network they are connected to? To what extent can functional specifications be set? What consequences would removal of the asset have for the system as a whole? Can an asset be tendered on functional specifications alone?
Public organisations	De mate van uitoefenen van 'beslisrechten' door publieke organisaties. Publieke organisaties hebben vaak andere belangen dan alleen maar het economische waarde van een dienst, waardoor het moeilijker wordt om een dienst uit de vrije sector aan te bieden.	1. Wat is de rol van publieke organisaties/opdrachtgevers voor deze asset? (aanbesteding, beheer & onderhoud, exploitatie?) 2. Welke rol speelt een veranderende regelgeving (en eisen) voor de functionele en economische levensduur. What is the role of public organisations in the supply of the underlying service/ management of the asset? Invloed uit kunnen oefenen op desbetreffende object.
Competition intenisty	Concurrentie intensiteit betekent de hoeveelheid leveranciers en hoe makkelijk het is om over te stappen naar een andere leverancier.	1. Zijn er meerdere leveranciers van de asset? 2. Is de opdrachtnemer vaak een aannemer of is er aanbod buiten de traditionele infrasector? 3. Zijn de leveranciers verticaal of horizontaal gebundeld? Is there an abandance of contractors/suppliers able to supply the asset or parts thereof? Are these suppliers mainly from the contruction sector or a variety of sectors? Are the suppliers vertically or horizontally oriented?

Commented [AS-B2]: Hier nog een vraag naar de 'keten van partijen aan de aanbodzijde'. De condities waaronder een gespecificeerde aannemer (onderaannemer) wel/niet verantwoordelijk kan zijn voor een deel van het systeem en hiervoor een andere PaaS kan aanbieden. Hangt samen met veel andere karakteristieken.

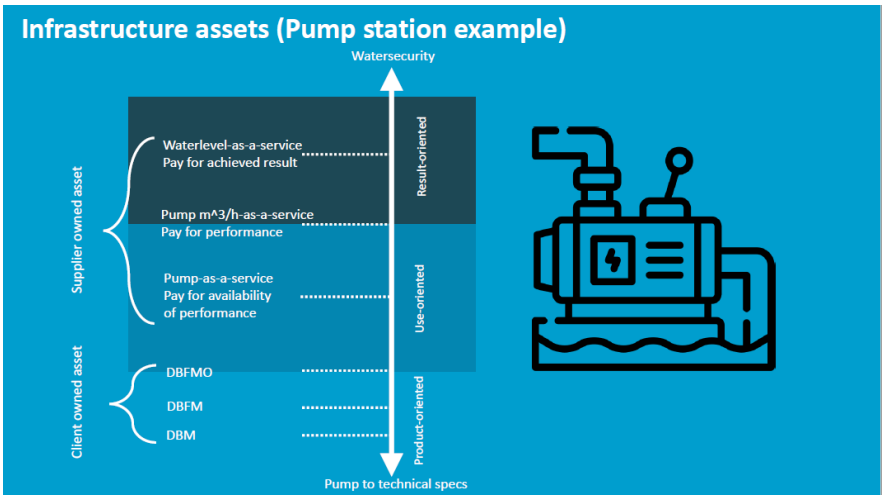
Commented [AS-B3]: o

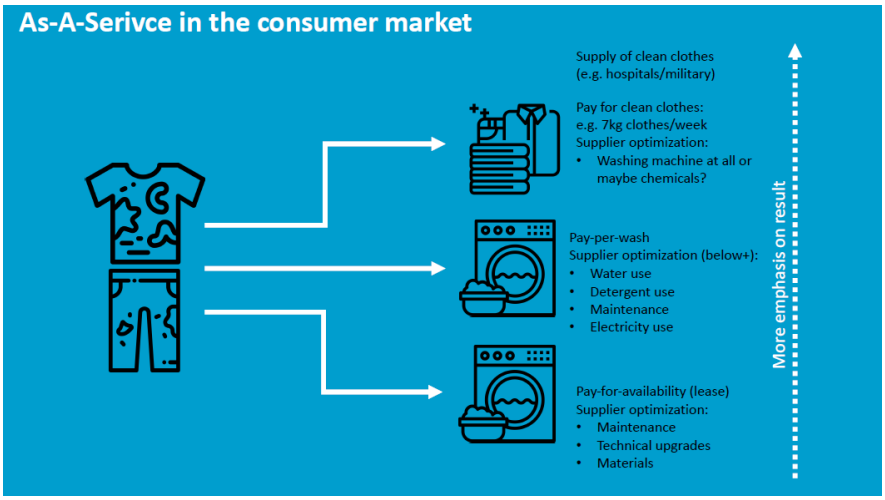
Commented [AS-B4R3]: Ook veranderende regelgeving en functionele eisen (en dus functionele en economische levensduur).

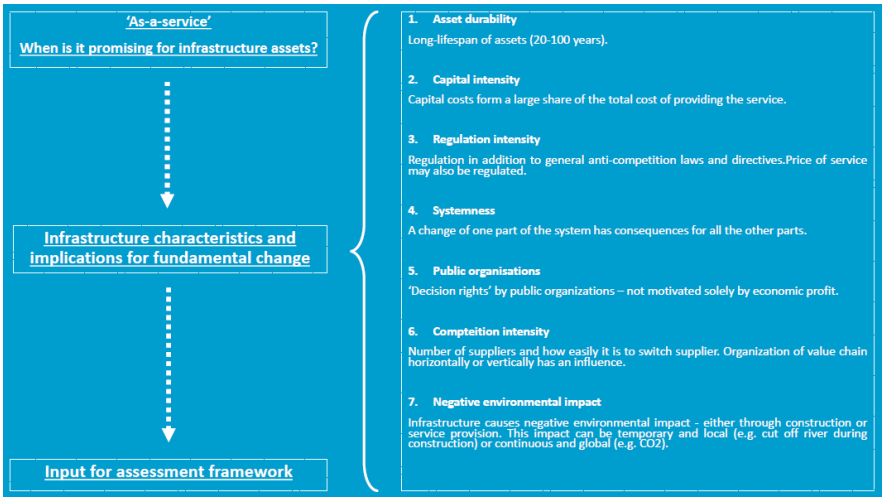
Negative environental impact	Infrastructuur assets zorgen voor zowel plaatselijke en kortdurige milieu impacts (aanleg) als langdurige en globale uitstoten zoals C02 (exploitatie).	1. Wat zijn de grootste milieu impacts en komen deze voort in de bouw- of exploitatie fase? 2. Zijn significante reducties in de impact haalbaar? 3. Op welke manier wordt de impact op het milieu in acht genomen? What are the foremost environmental impacts caused by the asset (in the contruction/operating phase)? Is there a potential for significant reduction of this impact? How is the impact on the environment taken into account?

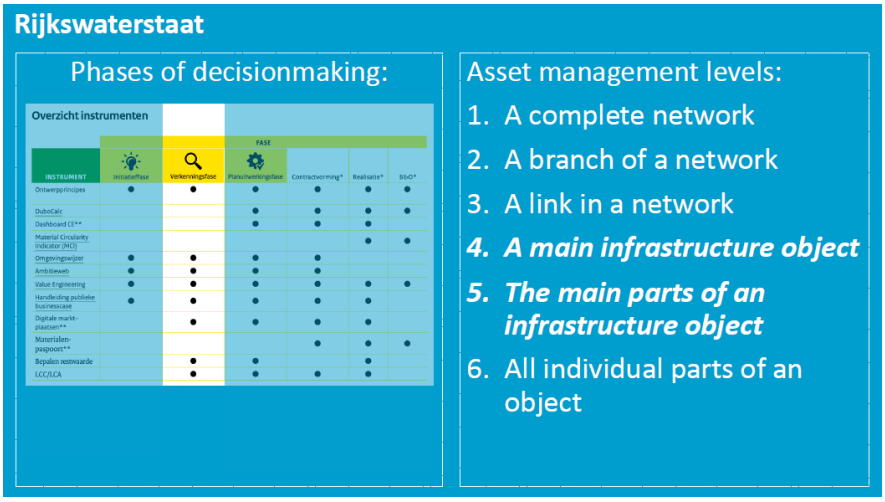
Bedankt voor uw tijd en deelname. Als u interesse heeft, zal ik de bevindingen van mijn onderzoek na afloop met u delen.

IV THE AS-A-SERVICE INFOGRAPHIC






'As-a-service'
When is it promising for infrastructure assets?
Infrastructure characteristics and implications for fundamental change
Input for assessment framework
1. Asset durability
Long-lifespan of assets (20-100 years).
2. Capital intensity
Capital costs form a large share of the total cost of providing the service.
3. Regulation intensity
Regulation in addition to general anti-competition laws and directives.Price of service may also be regulated.
4. Systemness
A change of one part of the system has consequences for all the other parts.
5. Public organisations
'Decision rights' by public organizations – not motivated solely by economic profit.
6. Compteition intensity
Number of suppliers and how easily it is to switch supplier. Organization of value chain horizontally or vertically has an influence.
7. Negative environmental impact
Infrastructure causes negative environmental impact - either through construction or service provision. This impact can be temporary and local (e.g. cut off river during construction) or continuous and global (e.g. CO2).


Rijkswaterstaat
Phases of decisionmaking:
Overzicht instrumenten
FASE
INSTRUMENT
Initiatieffase
Verkenningsfase
Planuitwerkingsfase
Contractvorming*
Realisatie*
Beo*
Ontwerpprincipes
DuboCalc
Dashboard CE**
Material Circularity Indicator (MCI)
Omgevingswijzer
Ambitieweb
Value Engineering
Handleiding publieke businesscase
Digitale markt-plaatsen**
Materialen-paspoort**
Bepalen restwaarde
LCC/LCA
Asset management levels:
1. A complete network
2. A branch of a network
3. A link in a network
4. A main infrastructure object
5. The main parts of an infrastructure object
6. All individual parts of an object