Building Bridges for Bridges

Towards a Participatory Approach for Tackling Large-Scale Societal Assignments in Project-Based Polycentric Systems:

The Case of the Large-Scale Rehabilitation Assignment of Civil Engineering Structures in the Netherlands

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by

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Preface

Dear reader,

This piece of work puts forth a concept which is in essence an accumulation of ideas over the past years applied on a very contemporary and relevant issue, namely that of the Dutch transportation infrastructure and the rehabilitation assignment of civil engineering structures such as bridges and viaducts. It represents a perspective on how large and complex problems consisting of many decentralised projects and autonomous actors with diverging interests can be tackled in our society. I am convinced that sociotechnical systems that are designed and operate with principles of participation hold the future.

In hindsight I realised that a large number of the articles referenced in this thesis is co-authored by scholars of the Delft University of Technology. How exciting it is to realise that my alma matter is such a prominent authority in the academic world related to the domain of civil infrastructures, technology policy and management and foremost the participatory systems thinking initiative. I hope that throughout my life I will be able to remain connected with this University.

A small thought experiment: from past to possible future and beyond

During the 20th century and in the run-up to the *'bouwfraude'* (construction collusion) the construction industry had adopted a form of self-organisation (self-regulation). Of course, by saying this, it is not the intention to justify collusion, but as it appears, the construction industry had astounding self-organising capabilities. Collusion practices emerged in the 1990's until the implementation of anti-trust law which prohibited pre-consultation; as a result cartel formation emerged. The concept of self-organisation was inherent to the Dutch construction culture during the 20th century and has played an important part in the reconstruction of the infrastructure in the post-war period. One could even say that the Dutch culture has a tendency towards self-organisation, for example the internationally famous *'poldering'* model of the Dutch is also based on principles of self-organisation and balancing individual and collective interests. The introduction of price competition, after the emergence of the Dutch procurement law as a consequence of the European directive, resulted in stagnating innovation, distrust and lacking collaboration. The procurement law ended the collusive practices of the Dutch industry, but at the same time resulted in short-term competition, stagnated productivity growth and systematic cost overruns and time delays.

What we now see is a transition towards the adoption of the *'old'* in accordance with the *'new'*, public actors seek to restore collaboration within the sector such that the inefficiencies can be overcome. With collaboration we do not mean that private actors should start colluding again but consider using the *'old'* self-organisation capabilities to improve the sector's productivity such as developing and sharing knowledge across organisational and project boundaries for collective benefit (the *'new'*). The proposed programme approach in this thesis can provide the means to facilitate this transition and perhaps in the end induce a more permanent change to the sector's culture or even its laws.

This might seem utopic on the surface, but given the history of the Dutch civil engineering sector it might just as well be plausible. The Netherlands has a track record of successfully accomplishing what at the time were considered to be impossible assignments by means of having a (shared) vision and well-organised collaboration. Think for example about the 'endless' land reclamation over the centuries, the continuous endeavour of building dykes and the delta-works that have been proclaimed to be a modern world-wonder. Perhaps with this in mind, this might not seem as utopic after all; nevertheless, this for the eye of the beholder to determine.

The evolution of complex systems

As food for thought before we delve into the content of this research, I would like to mention the internet as a model for the evolution of complex systems and share the following thoughts.

> Could the development of the internet, as it is today, have happened if it were managed by only one authority? And if you would tell its founding partners, at the time of creation in the early 80's, about how complex it has become, the general dependency of society as a whole on the internet and the uncountable innovations it has facilitated; would they be able to comprehend this at the time? Or even, would they be able to design the internet in its current form from scratch? Most probably not. It required a relatively simple idea and infrastructure to evolve – based on a relatively simple set of low-level protocols – into an entangled 'mess' on which almost all society's utilities depend and where information is the new gold.

This same concept of development, I believe, is inherent to complex systems and it is the fundament on which the proposition of this thesis is built. More specifically, how can the civil engineering sector realise a complex solution to address the challenges of the rehabilitation assignment?

A word of gratitude

I would like to express my sincerest gratitude to the following people:

- Papa, mama, Patrick and the rest of our family;
- Anne and her family;
- My dearest friends. You know who you are;
- My graduation committee: Frances, Iulia, Pieter and Jan for challenging me academically and being flexible and supportive along the way;
- Emile, Pjotr and Henrie for stimulating my development and giving me the opportunity to become part of the civil engineering sector that I am dedicated to help improve;
- Everyone else that contributed to the development of this thesis in some direct or indirect way!

THANK YOU!

Alexander Bletsis
April 20th 2020, Utrecht

Executive summary

We cannot solve our problems with the same thinking we used when we created them – Albert Einstein

Problem statement

The Dutch civil engineering sector stands at the foreground of a large scale assignment for which it is not ready. More specifically, the sector is confronted with the rehabilitation assignment of civil engineering structures that were built between 1950-1980. Estimates indicate that within this timeframe 40% of the existing bridges and viaducts were constructed – about 16,000 to 40,000 of them. Rehabilitation refers to the following aspects:

1. Bridges and viaducts need to be appropriately monitored and inspected such that their condition can be established;
2. Many ageing bridges and viaducts need to be renovated or replaced as they do not meet the functional and technical requirements.
3. All bridges and viaducts need to be maintained. However, deferred maintenance of bridges and viaducts has been ramping up for many years.

However, besides the sheer number of upcoming projects that strain the control and management of infrastructure operation, there are other challenges associated with this rehabilitation assignment. Namely:

- The current project-centric approaches are unable to deal with the increasing in complexity of rehabilitation projects and lead to cost overruns and time delays;
- The increased social and institutional complexity due to short time horizon and decentralised institutional character that lead to impasses and little action;
- Lack of trust and high degree of competition that lead to Insufficient resources for innovative solutions and increased productivity.

Therefore, governance and coordination that is able to mobilise the sector as whole is needed in order for these challenges to be addressed.

Trends and opportunities

For the past years, the aforementioned issue has been a hot topic of debate in the sector and multiple initiatives have been put into motion with the goal to devise strategies with which rehabilitation assignment are tackled. Among others, the three most important that were identified are ‘de bouwagenda’, ‘DigiDealGO’ and ‘de Marktvisie’. In summary, these initiatives plea for more standardisation, digitisation, innovation, knowledge development and sharing, collaboration and institutional and cultural renewal to overcome the barriers that withhold the sector from realising the necessary productivity growth. Yet, these initiatives have thus far not been successful to unite and reform the sector. This is attributed to collective action problems related to diverging interests and a

lacking sense of urgency. Nevertheless, the existing trends and opportunities should be leveraged to develop a comprehensive solution that is able to address the challenges of the rehabilitation assignment.

Proposed solution

Given the needs, desires, values and requirements obtained from the synthesis of theoretical and practical insights, a conceptual framework of governance and coordination was designed. The premises on which this framework rests is to provide an approach that:

- Is able to build on existing initiatives and approaches related to civil infrastructure rehabilitation;
- Acknowledges that the civil engineering sector is a project-based industry that consists of multiple autonomous yet interdependent public and private actors with diverging interests;
- Provides a stepwise transition towards an implementable solution that is able to adapt to changing contexts;
- Acknowledges that participation of the sector is needed for collective action to be established, implying that appropriate incentives that lead to a collective mission and collective interests needs to be devised;
- Realises an increase in productivity when cross-project coordination and interorganisational collaboration is facilitated.

As a result, the framework consists of process, institutional and technological components that come together over time and guide the development and implementation of a programmatic approach wherein multiple projects are governed and coordinated as such to achieve higher-order strategic objectives. Namely, the development, diffusion and adoption of knowledge and innovations enabled by agreed-upon standards and Information and Communication Technologies.

Resolving design complications

Two key design complications had to be resolved. First, programmes are traditionally governed and coordinated in a hierarchical and central fashion by means of a Programme Management Office that is embedded in its host organisation. Given that the civil engineering sector has no formal hierarchical organisational structure, an organisational structure is needed that is able to retain a sufficient degree of autonomy and decentralised coordination while facilitating the establishment of long-term collaborative practices. Such structures are hybrid organisational structures of which their embodiment is dependent on the system's characteristics. Second, for collective action to be possible, collective action problems need to be resolved. Thus, also implying that the process leading to the design of the rehabilitation programme needs to facilitate iterative deliberation and participation of the involved actors. This complication is resolved by introducing a process design consisting of multiple decision-making rounds in combination with empowering participation through trust, self-organisation and network governance.

Implementation advice

If the conceptual framework is applied correctly onto the rehabilitation assignment, governance and coordination can facilitate the development and implementation of a networked approach with which the challenges of the rehabilitation assignment can be addressed. By means of expert interviews and the conceptual framework the following implementation advice is formulated:

- Embrace the decentralised institutional character of the civil engineering sector and organise for a level playing field, but initiate according to the principle 'think big, act small';

- The transition towards a networked approach should be gradual, that builds on project and portfolio approaches to facilitate the sector's readiness;
- Regional and local public actors should take initiative and provide facilitative pilot projects and portfolios;
- Combined strategies should be leveraged that take into account the interrelatedness of criteria for productivity growth;
- Focus on organisational changes that stimulate collaboration and remove barriers such as individual interests and competition by means of institutional reform.

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1. Introduction

Governance and coordination to address the challenges of civil infrastructure rehabilitation

1.1 Control and management of civil infrastructures in the Netherlands

Civil infrastructures constitute the public infrastructures that supply societies with their basic needs. In this thesis the focus is put on the control and management of the transportation infrastructures in the Netherlands, more specifically, the rail network, the road network and waterways, such that the modern day challenges imposed on the civil engineering structures can be efficiently dealt with. Civil engineering structures are referred to as the structures that support the operation of the transportation infrastructure such as bridges, viaducts, locks, tunnels, weirs, quay walls etc.

1.1.1 The Dutch civil engineering sector

The Dutch civil engineering sector (or in Dutch the GWW[1]) is responsible for the control and management of the civil engineering structures that facilitate the infrastructure's operation (figure 1). The sector consists of multiple public and private actors. Namely, asset owners (national, regional and local governments), asset managers (national government agencies and departments of regional or local governments) and service providers (contractors, suppliers and engineering consultancies) (Volker et al., 2012). Moreover, these actors interact with one another to ensure the functioning of the infrastructure system according to an institutional infrastructure (Ottens et al., 2006).

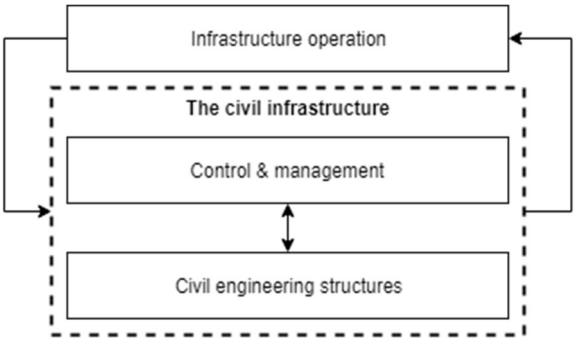

Figure 1: three layers of the infrastructure system adopted from Bouwmans & Weijnen (2006). The civil infrastructure consists of the control and management (civil engineering sector) and its civil engineering structures. The combination of those two facilitate infrastructure operation. On the other hand, the infrastructure operation influences the control and management of the civil infrastructure such as through changing use conditions and user demands (e.g. less hinderance) but the operation of the infrastructure is also responsible for its wear over time.

[1] GWW: acronym for Grond- Weg- & Waterbouw; Or in English, Ground- Road- and Water-construction.

In the Netherlands, the civil infrastructure is compartmentalised according to (interconnected) local, regional and national infrastructures and managed by their respective public actors. More specifically, the civil engineering sector includes government agencies such as Rijkswaterstaat and ProRail on the national level both whom report to the Ministry of Infrastructure and Waterstate, 12 Provinces and 21 Waterboards on the regional level, and 355 Municipalities on the local level. Thus, implying a decentralised institutional character where each public actor is responsible for its own infrastructure policy. On the other hand, the main source of service provision originates from 'the market', consisting of private actors – corporates and small & medium enterprises specialised in different areas of expertise – that compete with one another in a project-based industry. The procurement of projects – any form of services, supplies or work – by public actors follows a prescribed process depending on the type of project and must abide European and Dutch procurement regulations (PIANOo, n.d.). Upon acquiring a project, the winning private actor (or a temporary consortium of private actors) engage in a contract with the contracting authority – in public procurement this is the public actor.

1.1.2 Rising concerns regarding the civil infrastructures in the Netherlands

During the 20th century, the Netherlands experienced an 'infrastructure boom', its emergence was not only related to the recovery of existing infrastructure in the post-war period, but also for anticipating future demands due to economic growth (Hertogh, 2013). Indeed, it facilitated an unparalleled socio-economic growth and technological developments that are noticeable as we transition into the second decade of the 21st century. However, the civil engineering structures that were realised at the time are facing a twofold of challenges. First, these civil engineering structures have undergone systematic underinvestment in maintenance which is paired with a lack of as-built data and control, resulting in deferred maintenance and uncertainties regarding the actual state of the infrastructure (Herder, 2010; Wijnia & Herder, 2011). This implies that the total amount of planning, work, costs and time required for the inspection and maintenance of these structures have been ramping up until this day, and risks of catastrophic failure are ever so increasing. Second, these civil engineering structures are approaching their end-of-lifecycle requiring renovation or replacement as they are subjected to modern functional and structural requirements due to increasing societal demands (Hertogh et al., 2018). Examples are:

- The transition toward a more sustainable society which requires fundamentally new ways of managing infrastructures;
- The implementation of digital technologies in the infrastructure to facilitate better management of infrastructures (e.g. Building Information Modelling and Digital Twins), new forms of transportation such as autonomous vehicles require an increased integration of communications and transportation infrastructures (e.g. 5G antennas on bridges and viaducts);
- Intensification of use conditions requires more robust and resilient infrastructures. Robustness implies that the infrastructure is able to guarantee structural safety, whereas resilience implies that the infrastructure is dynamic in its operation and thus able to reduce hindrance when structures of the infrastructure need to be rehabilitated.

The combination of these two challenges is, in this thesis, referred to as the rehabilitation assignment of the Dutch civil infrastructure. Rehabilitation is an umbrella term referring to the inspection, maintenance, renovation and replacement projects associated with the control and management of civil infrastructures and their structures. The total cost for this assignment, according to the EIB (2016; 2017), is estimated at around €250 billion in the period 2015-2030. One large factor in this estimate is the large number ageing bridges and viaducts that need to be rehabilitated to ensure that the infrastructure is able to operate at its required capacity (Een vandaag, 2018; NOS, 2019a).

1.2 Complexity and the rehabilitation assignment

The above mentioned challenges exert substantial strain on the control and management of the transportation infrastructure. This is because of the increasing amount and complexity of rehabilitation projects. Project complexity is, among other sources, associated with the increased scope of projects, the involvement of multiple interdependent actors, political sensitivity and uncertainties (van Marrewijk et al., 2008; Hertogh & Westerveld, 2010) leading to 'wicked' circumstances (Rijsdijk et al., 2016). As a consequence, the inability to cope with the increasing complexity in rehabilitation projects leads to cost overruns, time delays (Hertogh & Westerveld, 2010; Jalali Sohi et al., 2016) and increases the risk of infrastructure malfunction due to human errors (Weijnen & Bouwmans, 2006).

However, in the grand scheme of things, the rehabilitation assignment has become a societal challenge with national allure that can only be overcome by means of collaboration across multiple public and private actors within the civil engineering sector (Landenwater, 2019). Nevertheless, mitigating this challenge, similar to most public policy issues, is not trivial and characterised by their social and institutional complexity and uncertainty (Rittel & Webber, 1973; Head, 2008). Furthermore, additional characteristics are associated to this societal challenge (Mertens, 2015) that add to social and institutional complexity and uncertainty:

1. There is a finite and shrinking time horizon within which action is possible.
    - Deferred maintenance needs to be dealt with in time to reduce the risk of structural failure;
    - Needs and desires of infrastructure operation are changing.
2. There are multiple government bodies involved that are responsible for their own infrastructure policy and multiple private actors that act on behalf of their own interests.
    - In the absence of a central authority there is no hierarchical relationship between actors that is able to direct a course of action.

The former characteristic increases the uncertainty and pressure in the negotiation and execution (project delivery) processes of the rehabilitation assignment. Whereas the latter characteristic increases both social and institutional complexity due to the and the absence of a central coordinating authority and differences in organisational structures, policies and individual interests of the national, regional and local public actors, and private actors.

1.2.1 Complexity and uncertainty demands viable governance and coordination

In other words, the socio-economic welfare of the Netherlands is under pressure as its civil engineering sector is confronted with a twofold of challenges – deferred maintenance and changing structural and functional requirements of its civil infrastructure and structures. Taking measures in an uncoordinated manner will most likely result in redundant efforts and inefficient planning and execution, and thus the sector will not have the available capacity to mitigate the assignment: there is a need for structural capital investments, innovative solutions, knowledge development and human capital given that the (unplanned) down-time of an important bridge due to deferred maintenance may lead to between €400,000 and €4,800,000 in losses each day due to traffic congestion alone (BouwendNederland, 2019).

As such, the different national, regional and local public actors – responsible for the control and management of their respective civil infrastructures – need to take coordinated action and take necessary measures to overcome the challenges of the rehabilitation assignment in close collaboration with 'the market'. Nevertheless, taking into account the social and institutional complexity and uncertainty that characterises the rehabilitation assignment, collaboration towards a viable solution is not trivial. Therefore, given that there are many similarities across multiple actors (both public and private – i.e.

low asset specificity with regards to civil engineering structures), the lack of resources and the need for knowledge development and innovation, the rehabilitation assignment can be tackled more productively if some form of governance and coordination is established.

However, as currently is the situation, in the absence of appropriate governance and coordination in the civil engineering sector to align interests and control uncertainties with regards to the rehabilitation assignment, impasses occur and little action is taken due to the fact that a societal challenge of this size is considered as 'too big to handle' (CoBouw, 2019c; 2020). Perhaps then, the 'challenges' of the rehabilitation assignment are not only its scale and the many and different types of projects that need to be undertaken. Even more so, challenges are: the decentralised institutional character and its associated complexities, the lack of trust and high degree of competition within the current civil engineering sector (Doree, 2004; Beuter, 2005). These challenges, make actors less assertive to coordinate activities and to collectively invest resources that lead to innovative solutions and increased productivity (Marktvisie, 2016).

1.2.2 Formulating research question

Claim – *Governance and coordination of the civil engineering sector supported by new innovations is able to facilitate the transition towards a more productive sector that is able to address the challenges of the rehabilitation assignment of civil engineering structures.*

The challenges as identified in the introduction are:

- Large number of rehabilitation projects due to changing functional and structural requirements and deferred maintenance;
- Increasing project complexity;
- Increased social and institutional complexity due to short time horizon and decentralised institutional character;
- Lack of trust and high degree of competition.

That if not appropriately dealt with result in:

- Strained control and management of infrastructure operation;
- Cost overruns and time delays;
- Impasses and little action;
- Insufficient resources for innovative solutions and increased productivity.

Considering the aforementioned, the following main research question is formulated:

Can governance and coordination be designed to address the challenges of the rehabilitation assignment and how?

2. Research Approach

Using critical systems thinking methodology to construct a viable conceptualisation of a governance and coordination framework to address the challenges of the rehabilitation assignment

2.1 Research Methodology

In this thesis the civil infrastructure system (figure 1), consisting of the physical civil infrastructures and the civil engineering sector that controls and manages the physical infrastructure's operation, is defined as a sociotechnical system. Sociotechnical systems are complex systems consisting of interacting physical and social subsystems that adapt over time due to changing contextual factors in its (inherently complex) environment (figure 2). Hence, it is reasonable to assume that, to be able to cope with the rehabilitation assignment, the civil engineering sector and the physical infrastructure – i.e. the sociotechnical system – will need to adapt into a system state that is viable in sustaining the infrastructure's current and future operation. Here, adaptation is seen as changes in the static and dynamic subsystems – also known as structures and processes respectively – that together constitute the system. In this thesis, an intervention arrangement is designed that intends to intend to shape or change the sociotechnical system or parts thereof. In particular, to address the governance and coordination issues, to understand the network of interdependencies within the context of the rehabilitation assignment and to cope with uncertainty, ambiguous information and conflicting interests (TU Delft, n.d.). Therefore, an appropriate research methodology, that facilitates the design of such an intervention, is formulated in the forthcoming sections.

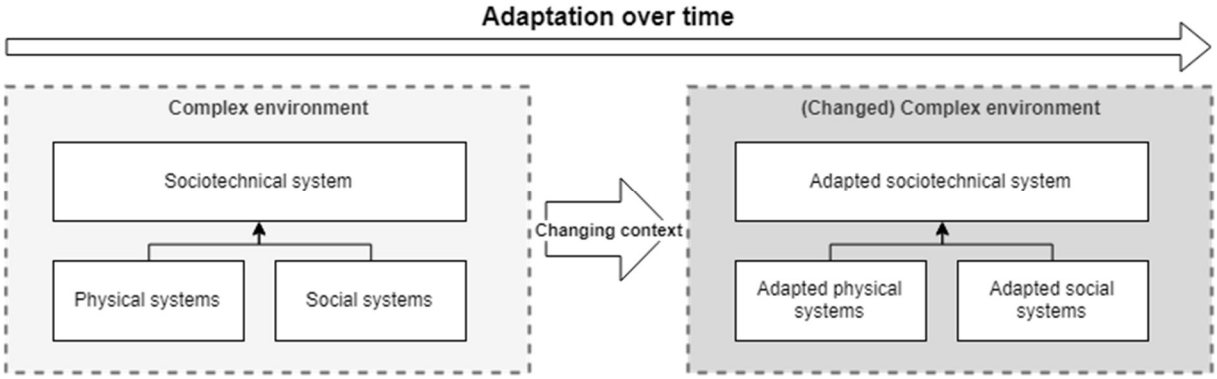

Figure 2: Visualisation of a sociotechnical system in a complex environment and adaptation as a process over time due to changing contexts. Adopted from Bouwmans & Weijnen (2006).

2.1.1 Research paradigm

The proposition of this thesis, is to intervene in a sociotechnical system (civil engineering sector) by designing a framework of governance and coordination that is able to address the challenges of the rehabilitation assignment. It should be noted that there is an inherent degree subjectivity associated with this research – some might even say in any research depending on one's epistemological beliefs. Hence,

the intention of this section is to describe in what ways subjectivity is embedded and dealt with in this research. More specifically, there are multiple ways of conceptualising the problem depending on the perspective of the observer – in this case the researcher. Additionally, the intervention arrangement consists of a subjectively filtered set of relevant practical and theoretical knowledge during the design process.

Critical systems thinking

In this thesis, the research approach constitutes the methodological considerations with which the research subject is analysed. Within systems thinking, different methodological approaches have been established to support different types of system analyses in a particular research. More specifically, *hard systems thinking* and *soft systems thinking* are the two dominant strands of systems thinking. The former deals with relatively well-definable problems and goal-seeking systems (Jackson, 2003 p. 47). On the contrary, the latter approach, deals with ill-structured problems and systems characterised by subjectivity where the emphasis on relationships between the system's parts is important (Jackson, 2003 p.187). *Critical systems thinking* refers to research approaches that leverages both hard and soft systems thinking (Jackson, 2001; 2003 p. 301). It is particularly useful due to the subjective and experiential nature of this research in its early stages which requires acquiring knowledge through interacting with and interpreting multiple world-views according to some (theoretical) 'framework of ideas' (Jackson, 2003 p. 187). Once the situation is sufficiently understood, a detailed and viable (explicit or implicit) model of the real world is constructed. Consequently, this knowledge is exploited to construct 'new' viable knowledge through designing new explicit models – such as an intervention arrangement. Therefore, three steps have been defined to support this process:

1. **Soft systems thinking** for researching and expressing the problematical situation, thus allowing for an immersive and interactive research from an interpretative perspective;
2. **Hard systems thinking** should be leveraged after a well-defined partial solution is formulated and used in the *design-process* of the intervention arrangement that intends to improve the system from a functional perspective;
3. **Soft systems thinking** is leveraged again in the final stages of the research, once hard systems thinking approach has yielded the intervention arrangement's design and an interpretative perspective is required to compare the design with the real world and suggest systematically and culturally desirable changes.

Constructivist epistemology

The process of constructing knowledge (viable concepts, models and theories of a real-world system) using critical systems thinking methodology, as described previous paragraph, adheres to a constructivist epistemological perspective. The inquiry of knowledge is the subjective process of engaging and interpreting reality and interacting with other subjective representations of 'reality'. That is to say that knowledge cannot be found or discovered read-made but has to be *actively* constructed by the cognising subject. Depending on the resolution & scope of the phenomenon, different knowledge representations may be viable. Hence, knowledge is dynamic, whereas the process of constructing knowledge (the act of knowling) is constant (von Glaserfeld, 1979). In constructivism, knowledge of reality is viable if *"it fits the purposive or descriptive context in which we use them"* (von Glaserfeld, 1979 p.14) – i.e. a model of a real-world system is viable if it adequately describes the observed phenomenon.

Iterative research process

Within this research project, substantial iterations were necessary for the constructed knowledge to be considered as 'viable'. It is an iterative process of which the first iterations are mostly explorative to get a grasp of the problem starting from a rather vague and low resolution understanding of: the area of concern, the framework of ideas that are or might be useful and the suitable methodology to approach – what is at the time perceived to be – the problem (figure 4). Through iterating and learning about the framework of ideas, methodology and area of concern, the research as a whole becomes more crystallised by means of constructing and reconstructing knowledge through interacting and actively participating in the research and research subject. Eventually, resulting in a coherent and sufficiently complete research capable of answering the formulated research question.

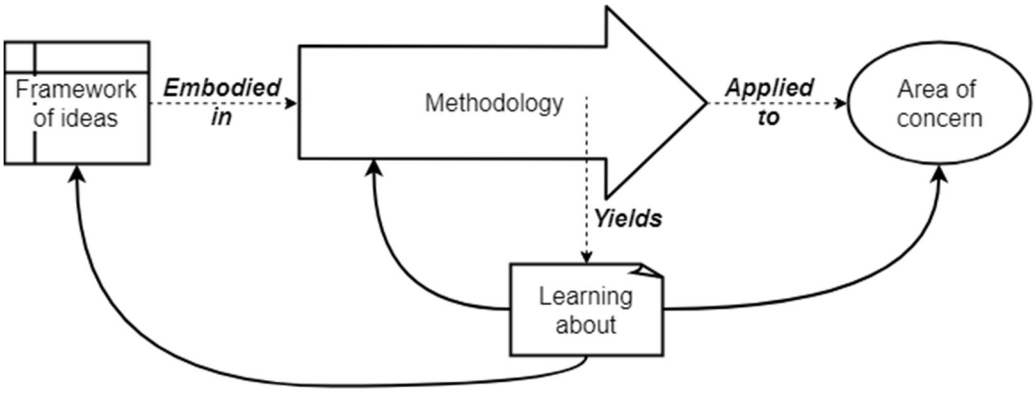

Figure 3: Standard research process adopted from Checkland & Holwell (1998). This research process has an iterative character as the lessons learnt by the methodology is fed into the framework of ideas, methodology and area of concern.

Given that the challenges associated with rehabilitation assignment of civil engineering structures is a contemporary and high profile problem in the civil engineering sector of the Netherlands, there was, and still is, no consensus on a solution. That is to say that a 'definite solution' – insofar a definite solution is possible – has yet to be found. Hence, the 'solution direction' of dealing with these challenges proposed by the civil engineering sector is dynamic and evolving rather than static. Consequently, doing research and participating in such a dynamic environment involved changing perceptions multiple times. Part of the research involved taking part in workshops and conferences, and engaging in discussions to test ideas and construct knowledge. In such a situation, the observer itself may have (willingly or unwillingly) an impact on the system (Heylighen & Joslyn, 2001).

2.1.2 Research scope and goals

The research subject must be appropriately demarcated by defining a scope and resolution. More specifically, in this research the civil engineering sector and the challenges associated with the rehabilitation assignment are viewed from the lens of problematic governance and coordination of (rehabilitation) projects and (public and private) actors in a project-based industry. Therefore, given that the rehabilitation assignment consists of many diverse rehabilitation projects, the lowest level of resolution is that of organisations (such as the defined public and private actors) and projects. Furthermore, to satisfy the methodology, four research goals are defined:

1. Gain an in-depth understanding of the rehabilitation assignment and civil engineering sector in the Netherlands, to address the observed challenges from a sociotechnical perspective;
2. Inquire and synthesise relevant theoretical concepts that address the observed challenges;

3. Design a conceptual framework of governance and coordination for the civil engineering sector (sociotechnical system) or parts thereof;
4. Address the validity of the designed framework.

2.2 Research methods

Based on the main research question, research methodology and goals, the following sub-research questions are formulated:

Sub-research question 1: **Which needs, desires, values and requirements for governance and coordination are relevant to the rehabilitation assignment?**

Sub-research question 2: **Can a conceptual framework of governance and coordination be designed to satisfy the identified requirements? And how?**

Sub-research question 3: **Can this be validated and how?**

To answer these sub-research questions (SRQ) appropriately, the respective research inputs, methods and deliverables are presented in table 1. The methods are described in greater detail in Appendix A.

Table 1: Sub research questions in relation to input, method and deliverable.

Sub research questions and their respective methods

SRQ	Input	Method	Deliverable
1	Academic repositories	Literature review	Theoretical needs, desires and values
	Internet search, conferences and symposia	Desk & action research (Checkland & Holwell, 1998)	Practical needs, desires and values
2	System requirements	Systems engineering (Brazier et al., 2018); Three-dimensional engineering design (Herder, 2010)	Conceptual framework design
3	Semi-structured interviews with experts	Qualitative data analysis (Braun & Clarke, 2006)	Validated conceptual framework

2.2.7 Research flow diagram

A research flow diagram is constructed according to table 1, that maps the chapters in this thesis, with the research questions and their respective inputs, methods and deliverables that contribute to answering the main research question (figure 4). The output of "research methodology & methods and questions" relates to the whole set of research questions and the main body of the research – i.e. the flow of the different methods. Furthermore, the main body's output is the input for answering the main research question, whereas the whole set of research questions is used as the input for the discussion. Finally, output of the whole research is used as the input for the conclusion.

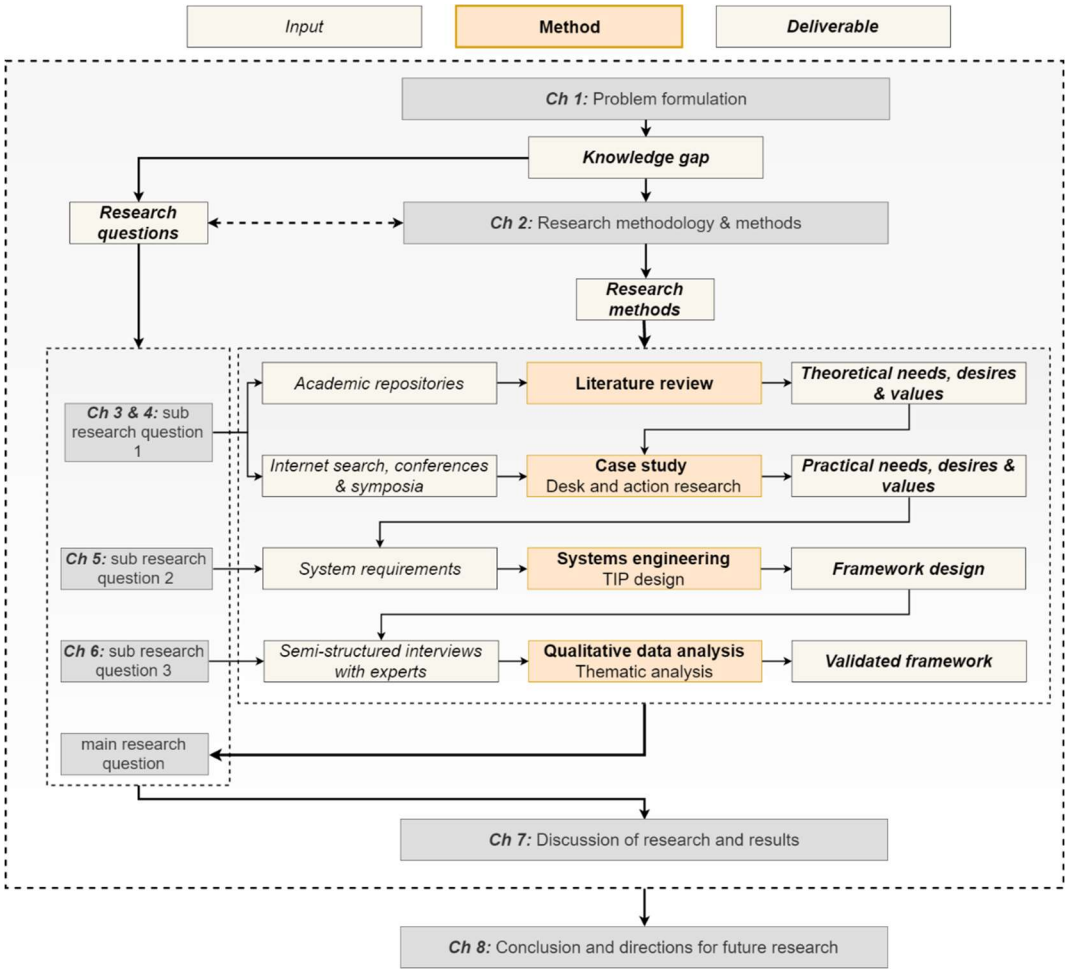

Figure 4: Research flow diagram of the thesis. The diagram visualises report structure in relation to the different research method and their corresponding (sub) research question(s).

3. Theoretical Inquiry

A synthesis of theoretical concepts to address the challenges of the rehabilitation assignment

In the introduction of this thesis the claim is put forth that governance and coordination of the civil engineering sector supported by new innovations is able to facilitate the transition towards a viable (more productive) sector that is able to address the challenges of the rehabilitation assignment of civil engineering structures. This chapter contributes to answering the first sub research question – *which needs, desires, values and requirements for governance and coordination are relevant to the rehabilitation assignment?* – from a theoretical perspective while taking into account the aforementioned characteristics of the civil engineering sector and challenges of the rehabilitation assignment.

More specifically, it introduces theoretical concepts related to project-based industries and projects to identify how governance and coordination are able to facilitate innovations and knowledge to flourish in and across projects. Furthermore, it specifies how, given the organisational characteristics of the organisation of the sector, governance and coordination should be leveraged.

The deliverable of this chapter is a synthesis of relevant theoretical concepts from which needs, desires and values are identified that contribute to the governance and coordination of the rehabilitation assignment.

3.1 Characteristics of project-based industries and projects

The construction industry, is a production system characterised by inefficient, fragmented, project-based and demand (pull) driven approaches (Vrijhoef & Koskela, 2005). Dubois & Gadde (2002), describe the construction industry as a loosely coupled system of projects and actors where the couplings represent different means of coordination – such as standards, communities of practice and procurement – that influence the productivity and innovation of the sector. Loose coupling refers to the way diverse elements (projects and actors) within an organisation (system of order – the construction industry in this case) are unified and coordinated; more specifically, as separated elements that are responsive yet retain their identity (Orton & Weick, 1990). Since the construction industry has a strong project focus, projects share few connections with other projects complicating across-project coordination and inter-firm collaboration thus hampering long-term productivity, innovation and learning (Dubois & Gadde, 2002).

Uncovering characteristics of projects to stimulate productivity, innovation and learning

Furthermore, to understand how the civil engineering sector operates as a production system, the characteristics of projects need to be explicated. Projects are defined as:

> *"a temporary organisation to which resources are assigned to undertake a unique, novel and transient endeavour managing the inherent uncertainty and need for integration in order to deliver beneficial objectives of change"* (Turner & Muller, 2003).

This definition encompasses essential features and pressures associated with projects that are outlined in table 2.

Table 2: Features of projects and resultant pressures adopted from Turner & Muller (2003)

A project	
Features	**Pressures**
Has an unique character: *No project is exactly the same.*	Projects are subject to uncertainty: *Potential mismatch between reality and expectation.*
Is undertaken using novel processes: *Processes of a project are not fully reproducible due to project uniqueness.*	Need for integration: *Project resources, project stages and organisations.*
Is transient: *Has a beginning and end.*	Undertaken project is subject to urgency: *Delivering desired outcomes[2] within desired timescale.*

When looking at rehabilitation projects as *temporary organisations*, implies that asset managers and service providers engage in a *transient endeavour* to which *resources* are assigned. These resources are selectively owned by the involved actors. Broadly, the resources allocated to projects are considered to be the information and knowledge, human capital, financial capital, materials and technologies required to facilitate the project process. Furthermore, civil projects are procured by service providers and originate from the asset management activities of the client – i.e. the asset manager (Volker et al., 2012). The aim of a project is to optimally meet the client's objectives and in case of unforeseen events adapt to the changing circumstances. The client's objectives, simply put, are a composite of quality, costs and time objectives (Barnes, 1988; Winch et al., 1998). Quality according to Winch et al. (1998) is a composite in itself referring to the quality of conception, specification, realisation and conformance to the previous qualities in practice (table 3).

Table 3: four types of quality in projects (Winch et al., 1998)

Four types of quality in projects	
Quality type	**Description**
Conception	Quality of the physical form; i.e. the end result.
Specification	Technical and performance standards expected within the project.
Realisation	The project process itself and techniques used.
Conformance	The degree to which the (expected) project execution adheres to the previous quality types.

In response to the clients objectives the project process is initiated; that is essentially the flow of information, within the project's organisation, that both specifies the character of the flow of resources and activities on site, and controls that resources and activities flow as specified (Winch et al., 1998). The stages within the project process are characterised as *'modulations on the overall information flow'*–

[2] This is in the definition referred to as objectives of change

i.e. different interdependent stage activities effecting the information content and form as it flows through the project process/lifecycle – (Winch et al. 1998) and need to be integrated appropriately such that the project can deliver the *beneficial objectives of change* (Turner & Muller, 2003).

Defining the objectives of change to create synergies across projects

In this thesis, *objectives of change* are interpreted as material and immaterial change to the civil engineering structure that is being considered in the project; such as inspection, maintenance, renovation or replacement projects. Material changes, are assumed to include physical changes such as replacing downgraded materials with new materials, adding new materials for reinforcement, replacing the asset in its entirety with a new asset, adding digital components for sensory purposes, cleaning the asset or adding technological innovations such as new standardised parts. Similarly, it may include assumed immaterial changes such as increasing the amount of available asset data and information, improved process knowledge or innovations in the form of new codified (explicit, organised and documented) knowledge.

Immaterial resources are non-exhaustive and widely applicable in multiple civil projects due to the relatively low asset specificity of civil engineering structures – i.e. assets share similar characteristics that may be exploited for synergies across-project[3] (Vrijhoef & Koskela, 2005). Stimulating the latter objective of immaterial change, is essential to the rehabilitation assignment since the diffusion and creation of new codified knowledge leads to productivity growth (Romer, 1990).

Exploit similarities and differences in projects for (technological) innovation

Finally, according to the definition provided by Turner and Muller (2003), (rehabilitation) projects are *unique* and *novel.* There is only one instance of that specific asset and its project context, which makes the project unique. This further implies that the project process of that instance is novel, or in other words, each consecutive project process is subjected to a variation since no project is exactly the same. Thus requiring adaptation of the process to the specific project context and gives room for differentiation. Even though projects are novel and unique, they also share significant similarities due to process similarities and low asset specificity. Therefore, for each similar project that is undertaken a variation in project processes occurs. It is through this variation that new data and information is gathered, new knowledge is generated and innovations emerge. In turn, the obtained knowledge and innovation are adopted in other project processes resulting in more variation and selection leading to the evolution of knowledge and innovations in projects (Rip, 2018).

3.2 A programme of projects as a stimulus for innovation in the rehabilitation assignment

The civil engineering sector can benefit from across-project coordination and interorganisational collaboration to improve productivity, standardisation and innovation. Across project synergies are oft-mentioned in programme- and portfolio-management (Jonas, 2010). There is a subtle difference between programmes and portfolios, namely, programmes are groups of projects managed on a more strategic

[3] The authors do not explicitly state synergies across-projects but mention reproducible and project-independent production system for the construction industry.

level whereas portfolios are managed on a more tactical level. Turner and Muller (2003) define a programme of projects as:

> *"a temporary organisation in which a group of projects are managed together to deliver higher order strategic objectives not delivered by any of the projects on their own"*

Whereas a portfolio of projects as:

> *"an organisation, (temporary or permanent) in which a group of projects are managed together to coordinate interfaces and prioritise resources between them and thereby reduce uncertainty".*

The strategic perspective of programmes fits the characterisation of the civil engineering sector as a loosely coupled system. On the other hand, portfolios are likewise applicable yet on a smaller intra-organisational scale where interfaces and resources are well manageable. Due to advancements in ICT, virtual organisations among participants allow the constituent projects of programmes to be physically distributed while realising additional benefits to both projects and its organisations by means of cross-project coordination that aims for global optimisation (Evaristo & Fenema, 1999). The definition of 'global optimisation' is related to the 'higher-order strategic objectives' and is thus dependent on the purpose of the specific programme. When adopting a programme approach within the context of the rehabilitation assignment, a valid interpretation of a higher order strategic objective could be to facilitate an overall productivity growth through developing and sharing knowledge, stimulating innovation and standardisation across projects. More specifically, three perspectives have been identified in support of adopting a programme approach in the rehabilitation assignment.

First, due to their scale programmes can boost innovation and as such provide standardised solutions and leverage more sophisticated project delivery methods; for example, the development of a lock archetype that facilitate learning and adaptivity across projects (Hertogh et al., 2018). Similarly, the concept of a digital archetype library and database of rail bridges provided significant improvements of structural inspection and assessment programmes in the United Kingdom (Griffin & Patro, 2018). Second, interorganisational cooperation across project boundaries and stable interorganisational relationships are drivers for innovation and innovation adoption respectively (Rutten et al., 2009). In line with the aforementioned, Winch (1998) mentions two sources of innovation in projects, both originating from the 'environment'; he suggests that innovation may occur either through adoption and implementation of existing innovations or as a consequence problem solving and learning (figure 5).

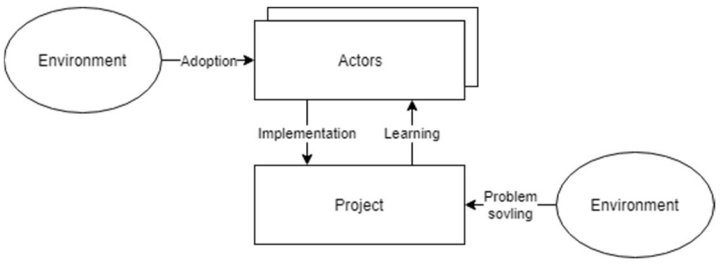

Figure 5: Two innovation mechanisms: innovation adoption and innovation through problem solving. Adopted from Winch (1998)

Problem solving in a project leads to innovation and learning by the project's temporary organisation consisting of the involved actors. The new innovation or obtained knowledge, in turn, leads to adoption and implementation of the innovation by other actors due to diffusion. Adoption is the decision of actors to integrate new innovations and knowledge in their organisation such that they are implemented in

concurring and future project. Whereas diffusion is the rate with which the innovation and knowledge is adopted by other actors (Rogers, 2010). Hence, programmes are facilitators of innovation diffusion and adoption, since collaboration between actors and coordination across-projects – between concurring and sequential projects – facilitates innovation (Doree & Holmen, 2004).

Finally, the third perspective is that of technological transitions, where projects are considered as *technological niches* in which (radical) variation is generated and programmes are considered as a *sociotechnical regimes* where innovations are selected and retained (Geels, 2002). The author describes sociotechnical regimes as relatively stable multi-actor networks guided by rules that coordinate activities such as technologies, standards, knowledge and processes, and facilitate innovations of incremental nature according to technological trajectories.

3.2.1 The programme lifecycle and its adaptation to contextual changes

A programme is a temporary organisation and its purpose to achieve a higher-order strategic objective and synergies across projects (Turner & Muller, 2003; Jonas, 2010). Thus, given the temporariness of a programme, it has a lifecycle that consists of multiple stages (Lycett et al., 2004; Haughey, 2009).

1. Programme initiation;
2. Programme planning and design;
3. Programme delivery;
4. Programme closure.

Given their long-term and complex nature, programmes are subjected to continuously evolving contexts (Rijsdijk et al., 2016). Hence, when developing a programme, it is of importance to consider the practical and contextual implications. More specifically, programmes are highly contextual that often evolve into maturity over time and not all of the programme's projects are executed synchronously (Lycett et al., 2004). Taking these points into consideration also provides opportunities for tailoring the programme solution to the specific needs of the organisations implying certain degree of scalability, flexibility and adaptability (Lycett et al., 2004). Adaptability and the ability to generate learning effects across projects and organisations are considered to be important benefits of a programme approach (van Herk et al., 2013; Rijke et al., 2014). Both adaptability and learning manifests in the implementation and execution of programme stages while maintaining feedback loops within the programme's organisation (van Herk et al., 2013). Adaptation implies aligning the programme and project strategies with (changing) contextual factors at either programme or project levels and cannot be seen in separation from coordination and governance (Rijke et al., 2014).

3.2.2 Diffusion of innovation and knowledge

Insofar the potential benefit of programmes as a mechanism for innovation and knowledge development, diffusion and adoption has been considered. Namely, for innovations to flourish, coordination across project boundaries and interorganisational collaboration is needed (Rutten et al., 2009). However, innovation is constrained if it is not appropriately facilitated within the superstructure of the civil engineering sector – which is defined as a project-based and loosely coupled system (Dubois & Gadde, 2002; Vrijhoef & Koskela, 2005). The innovation superstructure consists of the asset managers (clients), asset owners (regulators) and industry associations (professional institutes) who represent the interests of service providers (Winch et al., 1998; Rutten et al., 2009).

More specifically, the clients within the superstructure represent the demand-side of innovation (asset owners and managers) and have the ability to stimulate innovation through public procurement (Edler & Georghiou, 2007). Yet fierce price competition and policy deficiencies caused the construction

industry to stagnate in innovation capacity when European and Dutch public procurement law was introduced in 2004 (Doree, 2004; Uyarra et al., 2014). Nevertheless, public procurement can still be a good enabler of innovation if focus on improving policies and better communication between contracting authorities (asset owners and asset managers) and contractors (service providers) (Rolfstam et al., 2010; Uyarra et al. 2014).

For a programme in the rehabilitation assignment to be a successful facilitator of innovation in the Dutch civil engineering sector, coordination and collaboration within a network consisting of public and private actors seems to be necessary such that innovations are diffused and adopted across projects. In this thesis this is defined this as the need for collective action and will be further elaborated in the next section.

3.3 Collective action in polycentric systems: towards polycentric programmes

If addressing the challenges associated with the rehabilitation assignment is desired, then collective action among multiple autonomous public and private actors with diverging interests over long time frames and within an uncertain environment is needed (van Bueren et al., 2003; Head & Alford, 2015; Chester, 2019). Collective action is defined as the coordinated action taken by a group of actors that benefits their individual and collective interests (Encyclopaedia Britannica, n.d.). However, if it is impossible for the actor's interests to converge, collective action is not feasible. Such a situation is defined as a collective action problem – i.e. the inability for collective action to occur due to the diverging interests of the involved actors (Encyclopaedia Britannica, n.d.; E. Ostrom, 2008). Therefore, there is a need for a sort of organisation in the civil engineering sector that is able to provide appropriate governance and coordination to align interests and control uncertainties.

Pareto optimal outcomes: coordination mechanisms as enablers for collective action

The main purpose of coordination is to manage the interdependencies between activities and actors towards a particular goal need to be managed (Malone & Crowston, 1994). To indicate why coordination is important, two widely known examples from the field of game theory described in the book written by Easley and Kleinberg (2010) are presented. The goal is to illustrate *the need for coordination*. The notion of a 'game' in game theory is any interaction between multiple actors in which each actor's payoff is affected by the decision of others. An actor's decision is referred to as a strategy and the payoff choosing a particular strategy is the quantified outcome given the chosen strategy of the other actor(s). The assumption in game theory is that actors act rationally and in accordance to their personal self-interest. Given this assumption, there exists an inherent tendency of actors within a game to display insufficient cooperative behaviour if there is no fundamental mechanism for coordination. This is the case with games such as the Prisoner's dilemma and Stag hunt (see Appendix B1). Here, due to the presence of self-interest and the absence of coordination, collective action is (near) impossible to achieve.

Moreover, the concept of pareto-optimal outcomes becomes relevant: "*a state of affairs is Pareto-optimal if and only if there is no alternative state that would make some actors better off without making anyone worse off*" (Encyclopaedia Britannica, n.d.). Within game theory, a state of affairs is interpreted as two actors interacting with a certain strategy. The pareto-optimal outcome is juxtaposed to collective action since it similarly includes the balancing of individual and collective interests. Furthermore, in the context of these examples, a collective action problem is any state of affairs that diverges from the pareto-optimal outcome. It becomes clear that in social interactions, coordination may help in overcoming collective action problems. It appeared that the type of coordination mechanism deployed is closely related to the type of interaction required in the particular situations.

Consequently, relating it back to collective action:

- From the *Prisoner's dilemma* the observation is made that the strong incentive of defecting cooperation due to personal gain needs be overcome; it is important to balance personal interest with collective interest such that collective action is facilitated.
- From the *Stag hunt* the observation is made that it is important to cooperate and set a collective mission such that a long-term objective resulting in a higher reward is preferred over short-term opportunistic behaviour resulting in a suboptimal outcome.

In general terms the need for coordination is related to the desire of facilitating the participation between two or more actors such that the pareto-optimal outcome – i.e. collective action – is achieved. In the rehabilitation assignment, participation is an important enabler due to the autonomy of the involved the actors. Hence, the organisational structure deployed by the civil engineering structure needs to coordinate the activities and resources of actors in such a way that collective action is facilitated.

3.3.1 Polycentric systems as an approach to solve collective action problems

The autonomy of the involved actors in the civil engineering sector, is associated with the decentralised institutional character. Thus, the Dutch civil engineering sector is characterised as a polycentric system. Polycentric systems, according to Vincent Ostrom et al. (1961) refer to systems that involve multiple interdependent public and private actors that formally have their own decision-making power. Consequently, in contrast to central governance, Elinor Ostrom (2009 p.409) promotes polycentric governance as a method for governing polycentric systems since the fitting of institutions to specific settings is crucial for the performance of such systems.

> *"Polycentric connotes many centres of decision-making which are formally independent of each other. Whether they actually function independently, or instead constitute an interdependent system of relations, is an empirical question in particular cases. To the extent that they take each other into account in competitive relationships, enter into various contractual and cooperative undertakings or have recourse to central mechanisms to resolve conflicts, the various political jurisdictions in a metropolitan area may function in a coherent manner with consistent and predictable patterns of interacting behaviour. To the extent that this is so, they may be said to function as a system"* (V. Ostrom et al., 1961)

Within the polycentric organisation of the rehabilitation assignment, the various autonomous public and private actors of the civil engineering sector constitute an interdependent system of relations that take into account the competitive relationships, enter into various contractual and cooperative undertakings. Given that the sector consists of both public and private spheres, it requires new approaches to market and government institutions that stimulate entrepreneurship and public development respectively such that they may lead to joint outcomes able to solve collective action problems through self-organisation while reducing strategic behaviour (such as opportunism) (E. Ostrom, 2008). The resolution of such collective action problems requires groups with a shared interest, repeated deliberation across actors to create new rules and norms, coordination and monitoring mechanism and conflict resolution mechanisms (Baldwin et al., 2018). Elinor Ostrom (2008) devised eight design principles for achieving collective action in polycentric systems:

1. Clear boundaries as well as the different actors and their rights should be defined; this leads to trust and reciprocity
2. Rules in use should allocate benefits proportional to inputs (costs); this ensures that participants are willing to contribute to keep the system well maintained and sustainable

3. Actors that are affected by the system should be able to participate in enacting rules; this leads to fairness and inclusivity
4. Besides trust and reciprocity, some monitoring and rule enforcement system should be in place; this contributes to the system's long-term sustained functioning
5. Robust governance mechanisms that facilitate gradual sanctions should be used; since proportional punishment based on reputation leads to more trust
6. Easily accessible and low cost mechanisms to resolve conflicts should be in place; such a mechanism facilitates the cohesiveness, interpretation and enforcement of the devised rules in use
7. Self-organised sub-systems/sub-groups should be allowed to devise their own rules and have them recognised to a certain degree; this leads to well-functioning self-organised communities
8. Governance activities in polycentric system should be organised in multiple layers of nested enterprises; this stimulates fit with local conditions and self-governing capacity of self-organised groups within the system.

3.3.2 Governance of programmes in polycentric systems

Rijsdijk et al. (2016) suggests that complex projects should be divided into sub-projects and managed collectively as a programme in order to cope with complexity and changing contexts. However, the rehabilitation assignment is much broader and cannot be conceptualised as a single large infrastructure project. Instead, one could argue that the rehabilitation assignment of civil engineering structures resembles an aggregation of many diverse and complex projects spread over multiple autonomous actors that together constitutes the civil engineering of the Netherlands. Here, in line with the definition provided by Turner and Muller (2003), the notion of 'multiple projects' is identified. Consequently, the question, how can such a programmatic approach be applied to the nation-wide rehabilitation assignment that spans across multiple autonomous actors within the polycentric civil engineering sector to stimulate collective action arises.

This thesis suggest that the rehabilitation programme should be viewed from a polycentric system's perspective. This is because actors in the system are not subjected to a hierarchical relation (Huitema et al., 2009), and thus the system is subjected to polycentric governance (Ostrom, 2009). Therefore, it is assumed that central and hierarchical governance is ineffective and does not facilitate collective action in such systems. Nevertheless, traditionally, programmes centrally governed by a Programme Management Office that facilitates the coordination, support and control of projects within the programme that leads to programme success by means of improving the information, cooperation and allocation quality, and average project success (Unger et al., 2012). Moreover, Programme Management Offices are deeply embedded in its host-organisation and thus also highly influenced by its politics (Hobbs et al., 2008). Drawing from the Room for the River programme, Rijke et al. (2014) indicate that multi-level governance, involving both central and decentral steering is in the case of a large infrastructural programme in the Dutch civil engineering sector, is more effective than top-down control. Therefore, actors within the programme should agree upon an appropriate governance with which a programme approach in such a polycentric system can lead to collective action and effective programme delivery, while simultaneously retaining sufficient autonomy among the involved public and private actors.

3.3.3 Hybrid organisational structures as facilitators of polycentric programmes

Neo-institutional economics distinguishes among three broad categories of organisational structures that govern the interactions among actors. Namely market, hybrid and hierarchical structures (Menard, 2012). The main difference between these forms of governing interactions between actors lies in the

deployed coordination mechanisms utilised by the actors and the degree to which strategic resources are pooled (figure 6) (Menard, 2012). Or in other words, the organisational structure is dependent on the degree of autonomy the actors wish to retain. However, in case of the latter organisational structure, the actors are not autonomous due to their hierarchical organisation. An example of a hierarchical organisational structure is that of a conventional corporate and its constituent departments or a centralised government.

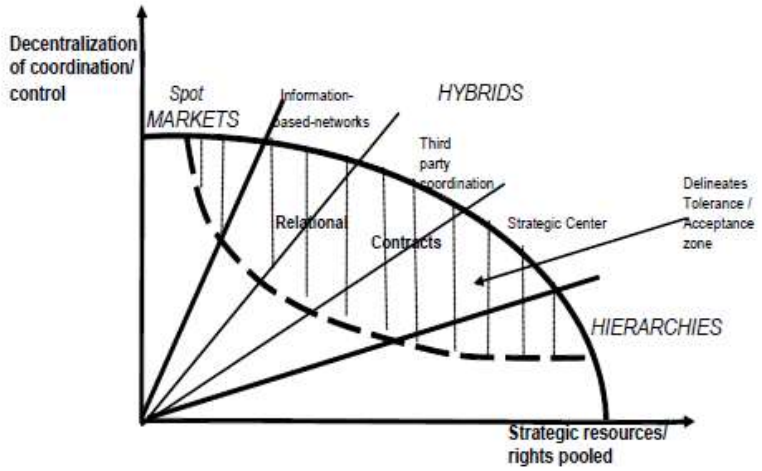

Figure 6: Schematic presentation of market, hybrid and hierarchical organisational structures with respect to decentralisation of coordination and strategic resources pooled. Adopted from Menard (2012)

In polycentric systems, selecting the appropriate governance mechanism contributes to the system's functionality through structuring the actor's interactions. In situations where coordination and long-term cooperation is desired, more long-term oriented relational contracts are preferred over short-term transactional contracts (Menard, 2012). Especially in situations with diverging or even conflicting interests among a set of diverse autonomous actors, a high degree of coordination is necessary (van Bueren et al., 2003). Therefore, polycentric programmes naturally lean towards a hybrid organisational structure where actors intensify coordination and engage in mutually beneficial relationships through transferring a certain degree of autonomy and strategic resources to an overarching organisational structure (Menard, 2012). As such, collective action problems can be overcome through participation in the sense that actor networks emerge in which actors forge interdependent (social) relationships leading to innovation and knowledge development and sharing (Dhanaraj & Parkhe, 2006; Menard, 2012).

To maintain cohesion among participating actors within the hybrid organisational structure, different governance structures may be exploited depending on the characteristics of the system – i.e. the degree to which actors are willing to sacrifice autonomy. For instance a pure network governance structure (Jones et al., 1997) or allocating a certain degree of coordination to a central entity – under the premise that is mutually agreed upon – such as third-party coordination or a strategic centre (Menard, 2012).

In the previous section a complication in the governance of traditional programmes was identified, namely, that central and hierarchical governance is ineffective in polycentric systems due to the fact that such authority is assumed not to be possible nor desired. Nevertheless, depending on the interpretation and implementation of a Programme Management Office it can be placed under a strictly hierarchical governance structure or some forms of hybrid governance structures – such as third-party coordination and strategic centres. Therefore, some form of Programme Management Office might still have a purpose in a polycentric system if the design principles proposed by Elinor Ostrom are adhered to (E.

Ostrom, 2008), albeit with certain limitations associated with the characteristics of the civil engineering sector – for example, given the decentralised institutional characteristics, the initiation of a Programme Management Office cannot be enforced by some central authority instead it has to be initiated through deliberation by the participating actors. Additionally, the Programme Management Office – due to the fact that it is highly embedded within its host organisation (Hobbs et al., 2008) – will require a new organisation to emerge, that is staffed by various public and private actors, and will thus be subjected to inter-organisational tensions.

3.4 The participatory systems paradigm

Participatory systems thinking is a new design paradigm based on the premise that connectivity enabled by technology is causing a transition towards a networked society where participation is becoming an important factor that influences the way systems are governed, coordinated and enable action (Participatory systems, n.d.). Similarly, the Dutch civil engineering sector is experiencing a transition towards the need for connectivity across organisational boundaries and projects to share and adopt knowledge and innovation is becoming increasingly important. In the previous sections different theoretical concepts are addressed that aim to structure the organisation of the rehabilitation assignment. More specifically, a (polycentric) programme of projects as a facilitator for the diffusion and adoption of innovation and knowledge across project and organisational boundaries, as a manifestation of collective action within a polycentric system and as a hybrid organisational structure consisting of interdependent autonomous actors.

In this section the concept of participatory systems is addressed as an embodiment for collective action within the context of the rehabilitation assignment and the civil engineering sector. Participatory systems are organisations enabled by technology in which actors actively participate to achieve a collective mission by means of acting, self-organising and coordinating their activities resulting in a manifestation of collective action. Therefore, this thesis proposes the following definition of a participatory system – in its essence a synthesis of the definitions provided in Appendix A2:

> *"A participatory system is a part of a distributed large-scale and networked sociotechnical system, and enabled by ICT. A participatory system consists of interdependent and interwoven social, communications and technical systems that aim to stimulate targeted actors to establish trust and to engage, self-organise and coordinate activities such that the collective mission can be achieved with explicit and/or implicit benefits for the larger distributed system it is embedded in." (own definition, see Appendix B1)*

In the following table the definition of participatory systems is mapped onto the rehabilitation programme based on the previous sections (table 4). The comparison of concepts fit seamlessly, strengthening the argument that the rehabilitation programme, given its polycentric characteristics, can best be organised as a participatory system. To further this argument, the main ideas within participatory systems are addressed in more detail in the forthcoming section subsections.

Table 4: Relationship between the rehabilitation assignment and participatory system by mapping the definition. By author.

Mapping the definition of participatory systems onto the rehabilitation programme	
Definition	**Rehabilitation programme**
Participatory system	The rehabilitation programme itself.
Part of a distributed large-scale and networked sociotechnical system	The Dutch civil infrastructure and civil engineering sector.

Enabled by ICT	ICT facilitates interorganisational and cross-project collaboration and coordination to achieve the higher-order strategic objective.
Consists of interdependent and interwoven i) social, ii) communications and iii) technical systems	i) The hybrid organisational structure, the multi-actor network, the autonomous actors and rules and regulation ii) the ICT architecture that facilitates the communication and coordination within the social system iii) The project processes, diffusion and adoption processes, technologies, civil engineering structures and other physical facilities.
Stimulate targeted actors to establish i) trust and to ii) engage, iii) self-organise and iv) coordinate activities	Targeted actors are asset owners, asset managers and service providers. i) Establish trust through agreements and trust mechanisms ii) Engage in reciprocal interactions within the programme iii) Self-organising communities within the programme to facilitate collective action iv) coordinate project related activities such as the diffusion and adoption of innovation and knowledge.
Achieve the collective mission	Overcome collective action problems and facilitate a more productive and knowledgeable civil engineering sector through the diffusion and adoption of knowledge and innovation across project and organisational boundaries.
Benefits for the larger distributed system it is embedded in	The societal challenge due to the large-scale rehabilitation assignment of civil engineering structures can be overcome.

3.4.1 Conceptualising participatory systems: the three-layered architecture

The participatory perspective aims to support actors of the system to partake in a larger whole forming a system-of-systems organised according to a three-layered architecture (figure 7) consisting of interdependent and interwoven social, communications and technical layers (Brazier, 2011; Rezaee et al., 2013). More specifically, the social layer consists of the actors, institutions, governance, strategies and other social structures. The communications layer is facilitated by distributed networked ICT and consists of the communication and information sharing structures and other digital systems that facilitate participation. The technical (also defined as the operations layer) layer consists of the technical processes, assets, and other artefacts (Rezaee et al., 2015).

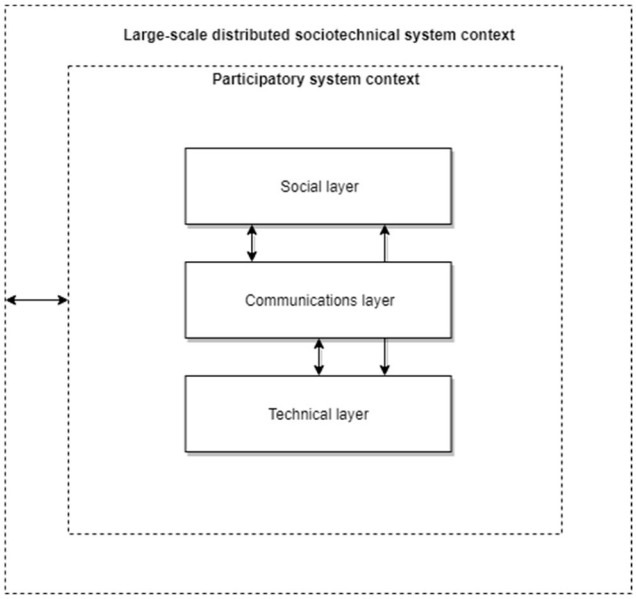

Figure 7: Three-layered architecture of a participatory system and its environment (adopted from Rezaee, 2013)

Finally, the interdependencies of these layers constitute the sociotechnical processes necessary to sustain the system's mission. It is important to design each layer in such a way that it can facilitate participation. This requires the formulation of rules and defining roles of actors, implementing an ICT infrastructure that facilitates reciprocal communications structures, and technical systems that enable the participation of actors according to the way these social and communication layers are designed (Brazier, 2011).

3.4.2 A rehabilitation programme: participation in the civil engineering sector

The civil engineering sector is a polycentric system, subjected to polycentric governance, where actors are autonomous systems with their own social, communications and technical systems. Consequently, the participatory system resembles the formation of a system-of-networked-systems between interdependent yet autonomous actors (Brazier, 2011). This demands a certain degree of similarity between these systems – i.e. compatible social, communications and technical systems – such that they are interoperable and can indeed be networked (Kurapati, 2012); thus requiring mutual agreements on technical standards, rules of engagement and trust such that participation can be facilitated. However, paradoxically, in polycentric system the transition towards a well-established participatory system will require participation of those actors to engage with one another and establish a participatory system while maintaining their (intra-organisational) autonomy and governance. Therefore, in the context of a rehabilitation programme, a participatory design process is necessary that in turn leads to participatory operational processes.

Furthermore, participatory systems alike all sociotechnical systems are subjected to uncertainty. Uncertainty, is defined as "*any deviation from the unachievable ideal of completely deterministic knowledge*" (Walker et al., 2003). In the line of this reasoning, it is impossible to know exactly where the participatory system is going (Brazier, 2011; Brazier et al., 2018). It is merely possible to provide the architecture for the design and operation of such a system in which participation can be facilitated. Moreover, the property of self-organisation is emergent and spontaneous and connotes that it can only be facilitated. De Wolf & Holvoet (2004) defined self-organisation as *"a dynamic and adaptive process where systems acquire and maintain structure themselves without external control".* Therefore, this requires the designed system to be adaptive and provide a bandwidth (system boundary) in which over time diverse *modus operandi* are possible (de Wolf & Holvoet, 2004).

Designing for this amount of variability of outcomes and where actors are actively shaping the system demands trust, awareness and the ability to (inter)act based on a high degree of local autonomy and coordination. This is also in line with the aforementioned design principles for collective action in polycentric systems of Elinor Ostrom (E. Ostrom, 2008). The mapping between design requirements for participatory systems and the rehabilitation programme are presented in table 5.

Table 5: Participatory systems are designed for trust, autonomy and interaction. These requirements are mapped onto the rehabilitation programme that is characterised by the theoretical concepts presented in this chapter. The design requirements are adopted from: the participatory systems initiative (n.d.))

Mapping of participatory design requirements onto the rehabilitation programme		
Design for:	**Requires:**	**Rehabilitation programme:**
Trust	Social acceptance, transparency, security	The process leading to programme design should be transparent and invoke trust through social acceptance by its participants.
Autonomy	Empowerment, self-management and self-regulation	Actors should be able to remain autonomous, establish rules and self-organise themselves within the programme.
(Inter)action	Engagement and collaboration	Interdependencies and interoperation among actors should enable them to initiate collaboration and collective action.

3.4.3 Shared situational awareness facilitates collective action in participatory systems

To reduce uncertainty in distributed sociotechnical systems – such as supply chains in the case of the article – it is essential to facilitate active information sharing and decentral coordination mechanisms that allow flexibility, (operational) alignment and rapid decision-making (Priya Datta & Christopher, 2011). In line with the definition of participatory systems, these aspects are supported by enabling Information and communication technologies, such as industry 4.0 technologies (Dallasega et al., 2018).

In participatory systems, a high degree in shared situational awareness among distributed and interdependent actors is desired. Shared situational awareness leads to better actual contextual information and better collective decision-making within the system; implying the ability to participate in joint corrective actions, and adapt while a problem occurs in the system (Kurapati et al., 2012). Based on the objectives presented by Kurapati et al. (2012), the goal is to achieve flexibility to adapt on the actor level, synergy for collective action on the subsystem level and innovation in processes and technologies on the system level.

Effective coordination leads to shared situational awareness, innovation, information availability, collective action and reduces uncertainties (van Bueren et al., 2003; Kurapati et al., 2012; Head & Alford, 2015) that occur in the programme lifecycle stages. Therefore, coordination positively contributes to the programme's performance (Rijke et al., 2014). Recent advancements in ICT facilitate across-project coordination such as virtual organisations (Evaristo & Fenema, 1999).

Furthermore, both central (top-down) and decentral (bottom-up, networked) coordination forms exist depending on the system's organisation, technologies and tasks that require to be coordinated. In participatory systems, decentral coordination is the preferred mechanism (Brazier, 2011). However, within a system, central coordination and decentral coordination may be used concurrently in separate activities depending on their characteristics – e.g. central coordination for material flow and decentral coordination for information sharing activities in logistical processes (Priya Datta & Christopher, 2011).

3.5 Synthesis of theoretical concepts

In the previous sections of this chapter a set of theoretical concepts related to governance and coordination are presented with which the civil engineering sector is characterised and the challenges of the rehabilitation assignment can be addressed. More specifically, the civil engineering sector is part of a project-based industry wherein lacking across-project coordination and interorganisational collaboration hampers innovation and productivity (section 3.1). To stimulate productivity and innovation a programmatic approach should be implemented consisting of four stages within which multiple projects are managed to achieve synergies and higher-order strategic objectives – such as the adoption and diffusion of innovation and knowledge across project and organisational boundaries (section 3.2).

However, for the sector to achieve such higher-order strategic objectives, collective action is needed (section 3.2 and section 3.3). Collective action implies that collective interests are established that in turn requires coordination and deliberation among the participating actors (section 3.3). However, the Dutch civil engineering sector is conceptualised as a polycentric system consisting of multiple autonomous yet interdependent actors that compete, cooperate and engage in contractual undertakings within a polycentric governance structure (section 3.3). Therefore, the traditional approach to programmes based on hierarchical governance for the (central) coordination, support and control of projects is considered to be ineffective; hence, a new approach to programmes compatible with polycentric systems is desired to facilitate collective action (section 3.3).

Consequently, a new organisational structure (governance structure) is desired that is able to facilitate a programmatic approach to projects in polycentric systems; one that is able to facilitate long-term relationships among actors while maintaining a significant degree of autonomy and decentralised coordination (section 3.3). The embodiment of these approaches – known as hybrid organisational structures – is dependent on the purpose and characteristics of the (polycentric) system (section 3.3). When looking at the initiation, design and coordination of a polycentric programme, participation is an important enabler of collective action by means of self-organisation. In this regard, participatory systems are distributed sociotechnical systems enabled by ICT – positioned within the context of a broader sociotechnical systems (in this case the civil engineering sector) – wherein the goal is to accomplish some collective mission by means of facilitating trust, autonomy and interaction (section 3.4).

3.5.1 Needs, desires and values from theory

The objective of this chapter was to formulate the needs, desires and values for governance and coordination to address the challenges of the rehabilitation assignment that stem from the theory (table 6). These, needs, desires and values should be specified as requirements. This is done in the beginning of chapter 5 where the theoretical requirements for governance and coordination are collated with the practical needs, desires and values.

Table 6: Needs, desires and values as identified from the theoretical concepts (Author's own deliberation)

Needs, desires and values from theory	
Needs	
	To facilitate across-project and interorganisational collaboration
	To increase productivity and innovation
	To coordinate and deliberate with participating actors
Desires	
	Implement a programmatic approach for synergies across projects compatible with polycentric systems
	Implement a new (hybrid) organisational structure
	Manage multiple projects to achieve higher-order strategic objectives
	Stimulate productivity and innovation through programmes
	Adoption and diffuse innovations and knowledge across project and organisational boundaries
	Establish collective action
	Maintaining a significant degree of autonomy and decentralised coordination
	Accomplish a collective mission through participation enabled by ICT
	Enable innovation through public procurement by improving policies and better communication
Values	
	Quality
	Autonomy
	Polycentrism
	Trust
	Reciprocity & interaction
	Adaptability
	Digitisation

4. Current Practices

An in-depth analysis of the Dutch rehabilitation assignment of civil engineering structures

In the first chapter, the Dutch civil engineering sector, rehabilitation assignment and its challenges have been introduced. In continuation of the specific case study, this chapter contributes to answering the first sub research question – *which needs, desires, values and requirements for governance and coordination are relevant to the rehabilitation assignment?* – from a practical perspective while taking into account the presented theoretical concepts in the previous chapter. These concepts provide a 'lens' through which one can look at the rehabilitation assignment. More specifically this thesis proposes that:

- The civil engineering sector is a project-based polycentric system characterised by a polycentric governance structure and its 'loosely coupled' nature, the latter complicates coordination across project and organisational boundaries;
- The rehabilitation assignment, requires collective action to increase the sector's productivity;
- Collective action is defined as the adoption and diffusion of innovations and knowledge across projects and organisations for which appropriate governance and coordination is required;
- Programmes of projects are able to provide higher-order strategic objectives such as collective action, however, traditional hierarchical governance and central coordination of programmes does not fit the polycentric nature of the civil engineering sector;
- Hybrid organisational structures and participatory systems are able to replace traditional approaches to programmes with an alternative approach based on horizontal governance and decentralised coordination enabled by ICT;
- Collective action occurs through self-organisation of actors and active participation in both the design and operation processes of programmes.

These propositions are taken into consideration in the analysis of the Dutch civil engineering sector and the rehabilitation assignment. More specifically, the Dutch civil engineering sector is revisited in more detail and from the perspective of a polycentric system. Next, the pressures of the rehabilitation assignment are analysed and current trends are identified. Finally, the institutional and cultural obstacles and mitigation strategies are identified.

The deliverable of this chapter is are practical needs, desires and values that are used (together with the theoretical needs, desires and values) to design a conceptual framework of governance and coordination in the next chapter.

4.1 The polycentric Dutch civil engineering sector

The construction industry in the Netherlands is mainly divided in civil engineering sector, utilities (hospitals, offices, schools etc.) construction sector and residence construction sector. The Dutch civil engineering sector (Grond-Weg-Waterbouw or GWW in short) is responsible for the control and management of the civil infrastructure and consists of public and private actors. More specifically, multiple public actors – Governments and Government agencies on national, regional and local levels – own and manage civil infrastructures and their civil engineering structures. In a polycentric system, each

public actor is autonomous and in control of their own infrastructure policies that facilitate (asset) management activities and the realisation of rehabilitation projects. Additionally, besides the involved public actors, private actors are themselves autonomous actors within the market whom are responsible for the delivery of rehabilitation projects. Private actors compete with one another to procure rehabilitation projects either in consortia or independently depending on the required capacity, resources and risks.

Consequently, even though these actors are considered as formally independent, manifestations of interdependencies between the involved actors exists. Namely, competitive and contractual relationships in the public procurement, acquisition and delivery of projects, cooperative relationships in (industry) associations, initiatives and within projects, interdependencies between public and private actors, and the different specialisations – such as the different service providers. Furthermore, on a more macro-level due to a limited market capacity and an increasing demand for rehabilitation projects cause additional fundamental interdependencies. A coarse organogram of the civil engineering sector is depicted in figure 8 and described in more detail in the following three subsections. Furthermore, a relational diagram was created as well and added to the appendix (see Appendix B3).

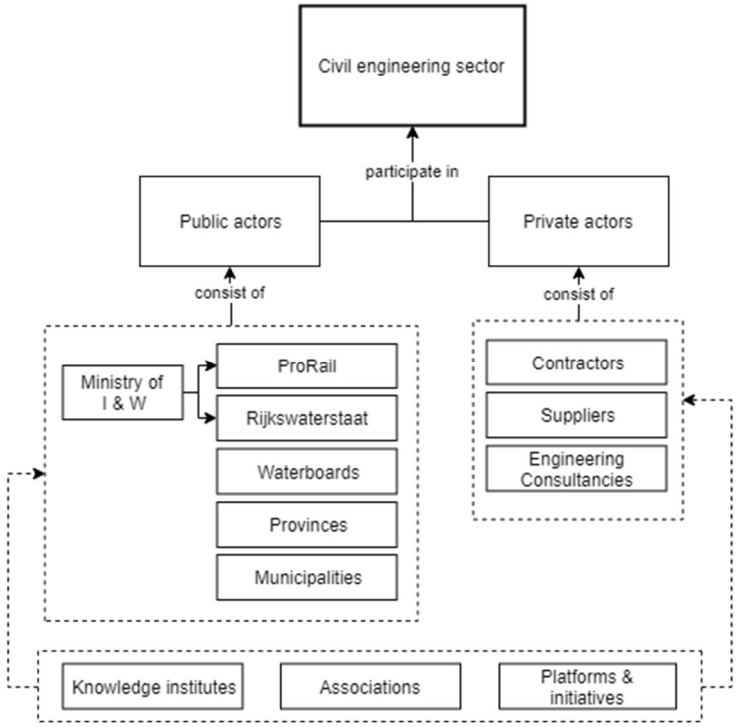

Figure 8: Organogram of the Dutch polycentrally organised civil engineering sector

4.1.1 Public actors

National level: Government agencies such as Rijkswaterstaat and ProRail are responsible for managing National water and road, and rail infrastructure respectively. Rijkswaterstaat is split in multiple (7 in total) regional organisations and has fragmented yet hierarchical structure regarding maintenance and renovation (Organsiational structure Rijkswaterstaat, n.d.). ProRail B.V. is a company owned and financed by the Dutch State whose management policy is approved by the Ministry of Infrastructure and Water state (such organisations are also referred to as quasi-government agencies). The Ministry of Infrastructure and Water state is the asset owner.

- ***National asset managers:*** Rijkswaterstaat, ProRail;
- ***National asset owner:*** Ministry of Infrastructure and Water state.

Regional level: Provinces and waterboards own and manage civil infrastructure and their engineering structures on the regional level. Provinces (12 in total) are regional Governments consisting of multiple municipalities whereas Waterboards (21 in total) are independent regional Governments that own and manage the Dutch water infrastructure including civil engineering structures such as bridges.

Local level: Municipalities (355 in total) are local Governments who own and manage their local civil infrastructure and engineering structures within their Municipal boundaries.

- ***Regional & local asset owners:*** Provinces, Waterboards and Municipalities;
- ***Regional Asset managers:*** Responsible executive departments of those Governments.

Regional and Local Governments are autonomous in incurring and financing their own rehabilitation projects in accordance with their infrastructure management policies (Nota kapitaalgoederen, see for example Nota kapitaalgoederen provincie Noord-Holland (2012)) that need to be approved by their respective Political councils. Waterboards are functional democracies and are responsible for their own financing and infrastructure management policies. Structuring their infrastructure policies is mandated by national-law (comissie BBV, n.d.).

4.1.2 Private actors

Contractors and suppliers: are actors mainly responsible for managing and executing projects, and providing the necessary resources for successful project delivery among which practical knowledge. In the sector a distinction between large contractors (e.g. VolkerWessels, BAM, Dura Vermeer, Ballast Nedam etc.) and smaller contractors is often made due to significant capacity and capability differences.

Engineering consultancies: are actors that consult private and public actors on their activities and processes based on their engineering expertise. Larger engineering consultancies

- ***Service providers:*** Contractors, suppliers, engineering consultancies

Private actors, depending on their core business and strategies; compete, collaborate, invest resources and procure (parts of) rehabilitation projects.

4.1.3 other stakeholders

Knowledge institutes: Universities (e.g. Technical Universities of Delft, Eindhoven, Twente and Wageningen), EIB (economic institute for the construction sector) and TNO are the primary knowledge institutes that conduct research and develop knowledge for the civil engineering sector.

Associations: associations for private actors such as 'Bouwend Nedederland' is an industry association for all contractors in the construction sector including the civil engineering sector. Associations for public actors such as the 'IPO' (Inter Provinciaal Overleg: interprovincial counsel), 'VNG' (Vereniging van Nederlandse Gemeenten: association for Dutch municipalities) and 'Unie van Waterschappen' (Union of Waterboards). In the realm of academic institutes, the 4TU federation is a collaboration among the four Dutch technical universities. Both public and private associations are organisations that represent and protect the interests of its member organisations in relevant political arenas and initiatives where long-term and decisive decisions are made and plans are drafted.

Platforms and initiatives: (Knowledge) platforms are digital and/or physical gathering places that facilitate the creation, distribution of knowledge or initiatives among actors. Platform CROW and platform WOW are notable platforms for public actors in the civil engineering sector. Another example is 'De bouwcampus'; a physical platform for co-creation and pre-competitive collaboration among public and private actors stationed on the TU Delft campus. The NEN (Nederlandse Normen; Dutch

codes) is a support organisation that establishes and maintains Dutch codes among which those of the civil engineering sector in close collaboration between public and private actors. Furthermore, initiatives such as 'de Bouwagenda' and 'DigiDealGO' are collective efforts of public and private actors that reside close to and sometimes originate from the political arena. These initiatives constitute the foundation for a sector wide transition towards a collaborative, sustainable, innovative and digitised civil engineering sector.

4.2 The rehabilitation assignment of Dutch bridges and viaducts

There is a large upcoming assignment for the Dutch civil engineering sector to maintain, renovate, replace and construct new civil infrastructure and structures. The total cost for this assignment, according to the EIB (2016; 2017), is estimated at around €250 billion in the period 2015-2030. One large factor in this estimate is the large number ageing bridges and viaducts that need to be rehabilitated to ensure that the infrastructure is able to operate at its required capacity (Een vandaag, 2018; NOS, 2019a). Therefore, a significant percentage of the budget is allocated to the rehabilitation of ageing bridges and viaducts. Of the estimated €250 billion, approximately 58% of the costs is related to the national, regional and local portfolio's that include bridges and viaducts; 72% of these costs are allocated to renovation, replacement and maintenance (EIB, 2016; 2017). An estimated budget of approximately €105 billion is allocated to all of the portfolios that include the rehabilitation of bridges and viaducts. Another estimate indicates that the price tag of the rehabilitation assignment is €4 billion on an annual basis (Appendix B4).

The rehabilitation works are split in three categories:

1. Bridges and viaducts need to be appropriately monitored and inspected such that their condition can be established;
2. Many ageing bridges and viaducts do not meet the functional and technical requirements imposed by new codes (for example the NEN 8700 code on structural safety (NEN, n.d.)) due to the changing use conditions related to an increasing traffic volume and load. Thus, existing bridges need to be renovated or replaced such that the capacity can be met. Public actors indicate to prefer renovation over replacement to avoid the destruction of capital (Core coalition roadmap 1, 2018; van Nieuwenhuizen, 2018; RWS & McKinsey, 2019)
3. All bridges and viaducts need to be maintained. However, deferred maintenance of bridges and viaducts has been ramping up for many years – Rijkswaterstaat alone has €873 million of deferred maintenance costs for the main road and water ways in 2018 (CoBouw, 2019a) and other public actors face similar problems (BouwendNederland, 2019).

Estimates of the civil engineering sector indicate that there are in total approximately 40.000 to 100.000 bridges and viaducts spread throughout the Netherlands (presentation dwarskrachten, 2018). Of these bridges and viaducts, approximately 40% (16.000 to 40.000) are built between 1950-1980 and nearing the end of their lifecycle (see figure 9). These bridges and viaducts in particular are showing signs of degradation due to their age, lack of systematic maintenance and intensified use conditions. As a consequence, bridges and viaducts are becoming less reliable in meeting their evolving technical and functional requirements causing an increase in risk of failing (Molenkamp, 2018; Uiterwijk & Molenkamp, 2019).

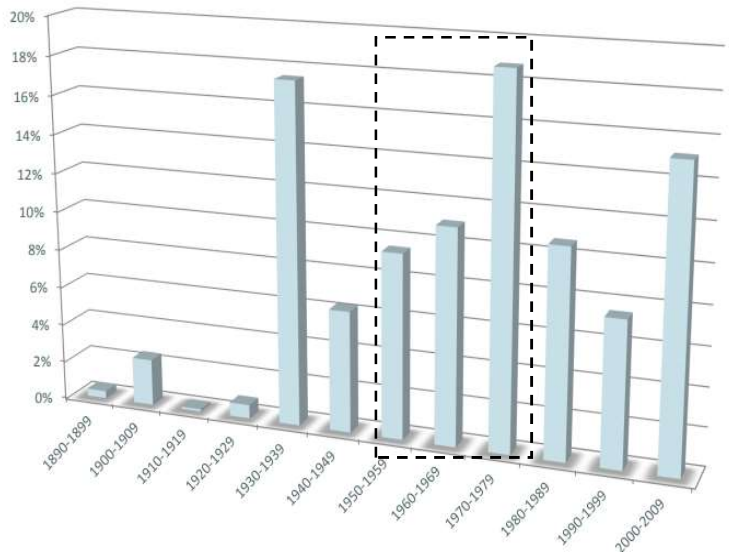

Figure 9: Age distribution of Dutch bridges, the columns in the dashed rectangle represent the total number of bridges constructed between 1950-1980 (Source: presentation Ingenieursbureau Westenberg B.V. for BouwendNed, 2015 p. 61)

The need for an approach that facilitates collective action

Due to the overwhelming amount of bridges and viaducts that are in their end-of-lifecycle, the increasing requirements in relation to changing use conditions and the demand for sustainability; a peak in the total amount of work to be done is expected in the near future – this scenario is depicted by 'scenario 1' in figure 10. Such a peak is unrealistic and disadvantageous for both public and private actors as it exceeds the capacity of the civil engineering sector, is too expensive and will lead high levels of hindrance in the transportation network. Therefore, the ambition is to move towards a scenario where the total costs are reduced and spread over time, and the peak is delayed to a point in the future such that the sector as a whole is given sufficient time for the sector to organise and develop viable solutions – this scenario is depicted by the green curve in figure 10. Although the aforementioned scenario (scenario 2) is attractive and seems to be necessary, reducing the costs requires an overall increase in the sector's productivity and spreading the costs over time requires a firm grip on the problem such that the less stringent cases of bridge and viaduct rehabilitation can be postponed to a later point in time (Molenkamp, 2018; Stroomversnelling bruggen, 2017).

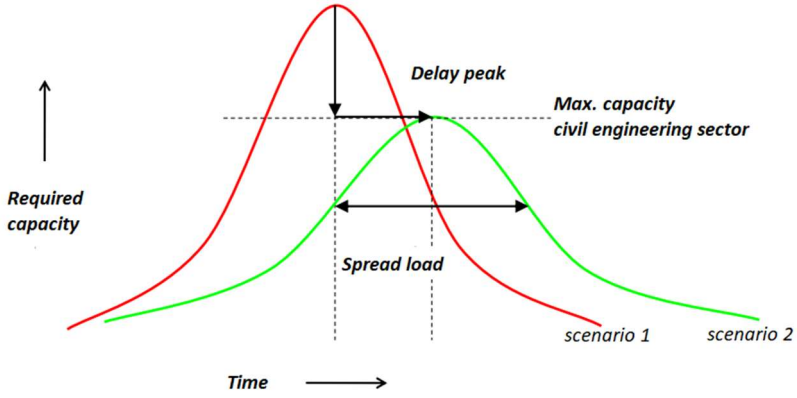

Figure 10: Schematisation of the required capacity of the civil engineering sector for the rehabilitation assignment as a function of time. Two alternative scenarios representing the current situation of (scenario 1) and desired situation (scenario 2) adapted from Molenkamp (2018).

Furthermore, the renovation and replacement assignment is characterised by its high complexity associated with the scale of the assignment, the increasing requirements on quality such as reducing hindrance and sustainability, financial constraints and the involved public actors from national, regional and local levels of government (Martkvisie, 2016; EIB, 2017). In turn the public actors face several uncertainties that additionally increase the complexity of the assignment. These uncertainties are related to:

1. The exact number of bridges and viaducts they manage;
2. The actual state of those bridges and viaducts and the actual use conditions to which they are subjected;
3. The structural properties of those bridges due to a lack of as-built information (Molenkamp, 2018).

Consequently, a well-organised and large-scale approach for the rehabilitation assignment of bridges and viaducts is necessary that is able to facilitate innovative solutions that improve the sector's productivity and grip on the problem (Talsma, 2019). However, for such a large-scale rehabilitation assignment to be orchestrated effectively, the participation of the whole civil engineering sector is said to be necessary (core coalition roadmap 1, 2018). Participation implies collaboration among the involved actors to coordinate activities, share data, information and knowledge, and stimulate innovation such that the assignment can be realised given the challenges and its complexity. 'De bouwagenda' is considered to be a steppingstone to realise this ambition on a National scale and make improvements towards collective action.

Box 1. De Bouwagenda: a nationwide initiative

"De Bouwagenda" is a construction sector wide initiative focused on the integration of the 2050 Paris agreement within the built environment that consists of 11 roadmaps. The agenda was brought to life late 2016 by the former Ministers Kamp (economic affairs), Schultz van Haegen (infrastructure) and Blok (living) with a letter to the Dutch House of Representatives (Tweede Kamer der Staten-Generaal) stressing the need for investing in collaboration, innovation and renewal of institutions (Kamp, Schultz van Haegen, Blok, 2016). The first roadmap: "*roadmap 1 bruggen & sluizen*" that is part of *"de Bouwagenda"* is oriented toward the renovation and replacement of ageing bridges, viaducts and locks. It has the following broad ambition (core coalition roadmap 1, 2018):

- Increase the sense of urgency for all public actors and on the political agendas;
- Better overview, insight and information uniformity of civil engineering structures in all of the Netherlands;
- Optimise the timing of rehabilitation projects to avoid failure but also the destruction of capital;
- Stimulate efficiency, innovation and scalability in rehabilitation assignment;
- Deal with fragmented knowledge and knowledge expansion through sharing;
- All civil engineering structures (bridges and locks) are renovated, circular and CO_2 – and energy-neutral in 2050.

Asset managers do not know the exact state of their bridges and viaducts, resulting in increased risk level (core coalition roadmap 1, 2018). Furthermore, the current knowledge regarding the impact of use conditions on the state of bridges and viaducts – i.e. there is not enough know-how to infer the actual state of bridges and viaducts, and when to intervene with either renovation or replacement. Additionally, the infrastructure, in light of climate adaptation and circularity ambitions of the Netherlands, must be made future-proof. Thus, there is a need for an efficient approach wherein the rehabilitation programme can be realised. This will require the average cost of each project to decrease. To do so, sufficient political awareness is required but also collaboration among public and

private actors such that the assignment is accomplished safely, innovatively and cost-efficiently. The programme, expected to last from 2020 to 2050, needs to stimulate and reward innovation for all of the involved actors such that the rehabilitation assignment is improved. Improved safety is accomplished by better grip on the problem as a result of asset management. A reduction in costs can be realised by an increase in productivity through innovation, sharing knowledge and collaboration.

4.3 Increasing the sector's productivity and grip on the problem

The construction sector ranks one of the lowest in terms of digitisation efforts (McKinsey & Company, 2016). Due to few developments in digital technologies, the labour productivity of the construction sector has experienced minor growth in the past decades in comparison to other industries (ING, 2016) – whilst the sector's human capital is shrinking, ageing and thus valuable sources of knowledge disappear (CoBouw, 2019c). However, in the past two years, there is an upward trend in productivity since 2014 due to an increasing amount of work (figure 11). As a consequence of lacking digitisation, many projects within the construction sector face cost overruns and time delays leading to losses in the billions of euros and result in low productivity within the sector (ABN AMRO, 2019). The causes for cost overruns presented in table 7 are remedied through the implementation of digital technologies that facilitate collaboration, innovation and learning.

Table 7: Main causes of cost overruns and time delays and suggested remedies. (Sources: McKinsey & Company 2016b; ABN AMRO, 2019; Cobouw, 2019b)

Cost overruns and time delays in projects	
Causes	**Remedies**
• Lack of communication • Insufficient control • No learning and knowledge development within project processes	• Active collaboration • Process innovation and standardisation • Learning and sharing of knowledge

Figure 11: Labour productivity in the construction sector compared to the industry and total of the Netherlands. (Source : ING (2018)

An increase in productivity within the construction sector is realised through the integration of disruptive ICT that enable efficient business processes (McKinsey & Company, 2017). Investing in process innovations improves project efficiency, reduce costs and are implementable in many projects leading

to more flexibility and *'learning on the job'* that in turn leads to further improvements (ING, 2016; ABN AMRO, 2018). Investing in digitisation facilitates such process innovations that provide many advantages such as better (predictive) maintenance, efficient design, reduction in mistakes and making small tasks more effective (ING, 2018). Therefore, private actors must invest in digital technologies to maintain competitive within the sector on the long term (Rabobank, 2019) and public actors must facilitate and invest in innovation to improve the control and insight over their civil engineering structures (Adriaanse, 2014). Additionally, public actors have the ability to facilitate this transition by actively 'pulling' innovations through the procurement of projects (EIB, 2017; RWS & McKinsey, 2019). The main benefits of digitisation are summarised in table 8.

Table 8: Benefits of digitisation classified according to primary contribution for public, private or all actors. (Sources: DigidealGO, 2019c; Digitaliseringsakkoord, 2018; Adriaanse, 2014; ABN AMRO, 2015, 2018; Core coalition roadmap 1, 2018; ING, 2016)

	Benefits of digitisation	
Actor	**Benefits**	**Examples**
Public actors	*Optimises codes, administrative and assessment procedures.* *Avoids costs of asset failure through better (real-time) insight.* *Optimises the operation and maintenance.* *Reduces hindrance through better asset availability during operation and rehabilitation.*	***Innovations in asset management*** Develop technology and tools that monitor, predict and assess bridges and viaducts using data, information and ICT. Stimulate uniformity across public actors by standardising asset management. ***Advanced modelling*** Construct sophisticated frameworks and models to assess and simulate the structural condition of bridges and viaducts under various use conditions (e.g. to find and exploit hidden strengths). ***Measure use conditions*** *Measure actual use conditions to generate insight and data that can be used in the abovementioned developments.* ***Measurement techniques*** Further develop and perfect non-destructive, destructive, lab and sample testing. Such as using advanced sensing. Expand codes to facilitate context dependent regulation.
Private actors	*Virtual environment that facilitates and optimises project processes.* *Reduce rework.*	***Integrated software & information*** Facilitates a well-functioning and interconnected enterprise architecture of organisation and between organisations such as contractors, suppliers and engineering consultancies (For instance, Model Based Systems Engineering.) ***Improved project process*** Building Information Modelling (BIM) facilitates digital project processes that improves project quality and reduces the possibility for making mistakes.
All	*Sharing of data, information and knowledge.*	***Network effects*** BIM is subject to network effects where its added value is dependent to the overall adoption of the technology within the sector; such as across-project coupling of information flows. As such, BIM should be combined in a system-of-projects. ***Process innovation***

Increases in productivity and reduction in costs.	Leads to process innovations that improve project efficiency and effectiveness, and are implementable in many projects leading to more flexibility and *'learning on the job'*
Improves the availability and uniformity of data and information.	***Non-linear productivity increase*** The combination of BIM and other digital technologies – for instance drone technology, Internet of Things (IoT) and Big Data – leads to further improvements in productivity.
Increases collaboration.	***Collaboration*** Facilitates online assessments, defragmentation and thus the sharing of knowledge.
Increases learning.	***Learning*** Processes become reproducible and continually improves projects through learning across projects.
Increases innovation (process and technical).	

The outsights toward a digitised civil engineering sector, are endorsed in the inaugural speech of Adriaanse (2014), he claims that digitisation will lead to innovations aiding in process reproducibility, integrated information management, collaboration among multiple actors (both public and private) and improved analysis of the infrastructure and its assets. However, for digitisation to be truly effective it should be uniformly implemented across the whole of the sector (ABN AMRO, 2015). For example, projects that use Building Information Modelling should be combined in a system-of-projects that, for instance, Rijkswaterstaat and ProRail – or any other arbitrary combination of public actors – can exploit in their information systems (Adriaanse, 2014). Other promising technologies that are complementary to Building Information Modelling are the Internet of Things (IoT), digital twins, sensor technologies, drones, market platforms, 3D-printing, computing and Big Data (ING, 2016; ING 2018; Rabobank, 2019).

Digitisation and informatisation has gained increased attention in the construction sector and public actors and private actors are investing resources in integrating digital technologies in their processes. The president of the *'Taskforce Bouwagenda'* has expressed the urgency to accelerate digitisation and informatisation since they constitute the boundary conditions for achieving the required productivity and facilitate sustainability in the construction sector (Digitaliseringsakkoord, 2018). Moreover, according to the DigiDealGO, digitisation and informatisation will lead to process innovations, quality improvements, mistake reductions, online assessments, defragmentation of knowledge, and a revitalised and more productive sector (DigiDealGO, 2019a; 2019b; 2019c).

Box 2. Digitisation and informatisation in the construction sector

The digitisation agreement

In 2018 a digitisation agreement was signed in line with 'de Bouwagenda' (Digitaliseringsakkoord, 2018). In order to boost productivity and innovation, advancements in digitisation and informatisation are necessary. However, a collaborative stance of the sector is needed to improve knowledge and competence in ICT. In doing so, incentives and open standards must be realised, and the sector must embrace collaborative, long-term and cross-project thinking.

DigiDealGO

From the aforementioned agreement, the DigiDealGO emerged. It is a national digitisation initiative for the construction sector. As of April 2019, the goal of DigiDealGO is to stimulate digitisation and

informatisation within the sector (DigiDealGO, 2019a). To speed up this process, DigiDealGO currently incentivises pioneering projects to share information and best-practices to set the example and contribute to the higher order objective (i.e. a uniformly digitised and renewed construction sector); these projects acquire a 'DigiDealGO stamp' (DigiDealGo, 2019b).
The long term ambition is to increase productivity and lower costs through innovative solutions by fully utilising digital technologies and open standards. However, this will require actors within the sector to participate and engage in the reciprocal exchange of data, information and knowledge. The principle for sharing is '*sharing data, unless…*', implying that data must be shared; unless there is privacy, safety or competitive sensitivity that requires its disclosure (DigidealGO, 2019c). Furthermore, digitisation requires a collaborative sector that is able to embrace change. Nevertheless, the willingness to strive towards digitisation is not sufficiently embedded within the culture and organisation of the sector (DigiDealGO, 2019d)
As a consequence, a culture change is required where emphasis is put on complementary collaboration across-projects in a competitive environment; where by *'working smart',* productivity is increased against lower costs (DigiDealGO, 2019d). This requires the sector to shift towards a fundamentally different form of collaboration, that of collaboration in networks that crosses the conventional organisational and project boundaries focussing on pooled resources. Within these collaborative networks, clear agreements on the ownership of data, type of data and accessibility of data needs to be made – i.e. clear rules of the game are necessary. Therefore, DigiDealGO proposes a network approach around central themes in digitisation where actors collectively work towards a shared goal (DigiDealGO, 2019d).

4.4 The rehabilitation assignment: a new impetus for the civil engineering sector

Through addressing the challenges of the large scale rehabilitation assignment: sustainability, digitisation and informatisation is believed to reinvigorate the civil engineering sector (e.g. Marktvisie, 2016; De Bouwagenda, 2017; EIB, 2017; Digitaliseringsakoord, 2018; DigiDealGo, 2019d; RWS & McKinsey, 2019). There is an increasing demand for collaboration, knowledge development and sharing, innovation and cross-project and sector-wide thinking such that the productivity and control within the sector can be improved. Approaches that implement portfolios or programmes are believed to facilitate this impetus since it involves multiple actors and long-term inter-organisational goals that span over multiple projects (EIB, 2017; core coalition roadmap 1, 2018; RWS & McKinsey, 2019) – albeit the differences between the two are at times blurry and not well understood. Therefore, this also implies that, besides digitisation and innovation, the sector should strive towards cultural change and reshape the way it is organised. Nevertheless, the *status quo* of the Dutch civil engineering sector has certain obstacles that need to be overcome.

4.4.1 Obstacles withholding the sector

From the case analysis, five broad obstacles withholding the civil engineering sector have been identified. More specifically, these obstacles are related to the behaviour of actors, the dominant project-focus, the existing rules and regulation, market structure and lacking sense of urgency. These obstacles are summarised in table 9.

Table 9: Obstacles withholding the civil engineering sector. (Sources: Marktvisie, 2016; IEB, 2017, Core coalition roadmap 1, 2018; DigiDealGO, 2019d, RWS & McKinsey, 2019)

Obstacles withholding the civil engineering sector	
Related to	**Description**
Actor behaviour	• Lack of trust and shared vision. • General resentment to change. • Information retention and opportunistic behaviour. • Prioritisation of individual interests above collective interests. • Lack of long-term strategy. • Loss and risk aversion due to unreasonable risk distribution. • Fight relationships within project contracts. • Insufficient communication between actors (e.g. in pre-competitive stages).
Market structure	• Hierarchical power relation between public and private actors. • Imperfect market conditions. • No incentives nor endorsement for innovation from public actors. • Ineffective use of reputation mechanisms and high focus on price in awarding contracts. • Low 'sector thinking' and high 'organisational thinking' which makes implementation of digitisation and innovation difficult. • high degree of short-term competition and strategic thinking is dominant.
Dominant project-focus	• Lack in collaboration due to short-term characteristics of projects. • Low profitability of innovations and uncertain return on investment. • No room for experimentation, new ways of working, digitisation and innovation due to tight project constraints and requirements. • No R&D budget leading to insufficient knowledge development. • Innovation is only stimulated if demand for innovation is project specific. • Low learning effects, development and sharing of knowledge across-projects is not part of the organisational strategy.
Rules and regulations	• The procurement-law limits the possibilities if not applied correctly. • Insufficient incentives for digitisation and innovation. • Fear to collaborate due to past 'construction-fraud' where private actors colluded. • Tight compliance and steering through contracts does not invite for new thinking and innovative entrepreneurship. • Insufficiently challenging and inconsistent public policies.
Lacking sense of urgency	• Insufficient perceived urgency to invest in digitisation and innovation collectively and across-projects; since digitisation and innovation is not on the top of the agenda (short-term wins are). • Little sense of urgency at the political and board level of public actors to invest in rehabilitation.

The presented obstacles are related to one another and influence one another. Therefore, the strategy for mitigating one obstacle needs to take into account the dynamic relationship with the other four obstacles. Take for example moving away from a dominant project-focus and moving towards the sharing knowledge and innovation across-projects within a rehabilitation programme. Besides shifting away from project-centric organisational structures to facilitate cross-project and inter-organisational knowledge development and sharing, it will additionally require changes in the behaviour of actors to move away from information retention and opportunistic behaviour; whereas the market structure and rules and regulations will have to change and facilitate a more collaborative environment in which the sharing of knowledge and innovation is incentivised.

4.4.2 Sector reform

The sector's initiatives such as 'de Marktvisie', 'de Bouwagenda' and 'DigiDealGO' have set the tone for the upcoming rehabilitation assignment; these initiatives speak of a '*revolution'*. Regardless of the obstacles, an impetus towards change has put the sector into motion. Where within the sector, aspects of collaboration, (process) innovation, standardisation, digitisation and the development and sharing of knowledge across-projects are highly valued. From the analysed documents, it is expected that, if implemented, that the aforementioned aspects will sufficiently improve the grip on the problem and productivity of the sector such that the upcoming assignment can be realised conform scenario 2 in figure 10. However, that is to say that the obstacles must be mitigated as well, otherwise the proposed measures civil engineering sector will remain a utopian vision set by optimistic policymakers. Therefore, institutional renewal is required in which the sector strives towards cultural change and reshape the way it is organised. These changes should leverage and continue to stimulate the upward trend in the sector's productivity (ING, 2018) while simultaneously being resilient to external (political) pressures and uncertainties such as the construction crisis of 2019-2020 due to issues raised with regards to Nitrogen and PFAS causing many construction projects to be halted presenting economic consequences to the sector as a whole (RTL, 2020; Bouwend Nederland, 2020).

Taking the aforementioned into consideration, this implies that certain changes in the sector's arrangements and the way actors organise themselves need to be facilitated. An overview of the of the combined proposed suggestions by the Dutch civil engineering sector is presented in table 10.

Table 10: Measures to improve the productivity of the civil engineering sector through institutional incentives, innovation arrangements and reshaping project. (Sources: IEB, 2017, Core coalition roadmap 1, 2018; DigiDealGO, 2019d, RWS & McKinsey, 2019)

Proposed measures for sector reform	
Procurement & Innovation arrangements	**Invest in quality and change** Public actors must want to invest in change (technological and organisational) and improved quality. Public actors can act as innovation pullers and incentivise private actors to invest in innovation. Likewise, private actors must want to exploit the opportunities and (co)invest in innovation and knowledge development while realising the network effects[4] of knowledge when shared. Developing knowledge and

[4] Knowledge sharing creates new knowledge, hence the knowledge in the network grows non-linearly.

	being able to control risk requires investing in productivity improvements, knowledge development and innovations. **Towards a collaborative culture** The sector should embrace collaboration and realise its benefits. This means, co-investing, providing room for experimentation, sharing risk and upscaling innovative approaches. The public actors should act as launching customers and facilitate this change. **Pre-competitive collaboration** Pre-competitive stage allows experimentation where actors can actively collaborate and learn from one another. **Involve innovative actors** Engage in collaboration with technologically developed private actors (also external to the sector). This increase input of technologically advanced private actors and stimulates standardisation, investments in innovation and R&D, and the professionalisation and innovation in organisational processes. Involve innovative small businesses with a lot of practical knowledge. **Open innovation, Research and knowledge development** Develop innovations together with sector that can be applied to projects separately. Similarly, develop knowledge platforms and databases that facilitate the sharing of knowledge through setting up initiatives for knowledge development and knowledge sharing and creating networks that stimulate innovation. The sector's industry associations and knowledge platforms should stimulate knowledge development across projects.
Reshaping projects	**Programmes stimulate innovation** Programmes function as platforms that support the development of innovative solutions across projects and facilitate synergies and information flow across projects. However, programmes require collaboration between public and private actors where long term objectives, shared responsibilities and profits provide a suitable environment to align individual and collective interests with multiple actors. **Batch similar projects regionally** Similar projects that are in the same region should be batched together requiring collaboration and coordination between public actors. Consequently, contracts are awarded to service providers based on technique, energy neutrality, circularity, innovativeness and price. **Stimulate experimentation & innovation** The intention is to give breathing room for experimentation and innovative solutions. Batched projects give the opportunity for service providers to invest in innovation. Hence, allows innovation due to multiplicity of projects leading to steady increase in productivity. **The 'rest' follows** Each time new knowledge or an innovation is generated, it is adopted by the sector. Thus, by embracing the new culture, the ambition in each project can gradually increase. This way new best-practices that are smart and cheaper emerge each round.
Institutional incentives	**Reform and standardise infrastructure policy** Public actors abide by their infrastructure policy ('nota kapitaalgoederen') that captures their maintenance intentions. This policy document should be reformed and

	standardised such that it stimulates public actors to be in control of their asset management capabilities. **Public actors should increase innovation ambition** Consistent policies over time but also among public actors. Additionally, regulation should be applied flexibly such that innovations are given breathing room, it increases the possibility for the implementation of process innovations and technological innovations. **Reliable short and long term perspective** Public actors are individually and collectively able to have a reliable overview on their asset management activities that facilitates action. This way, improved organisational and political awareness is created and the sense of urgency is increased. **Continuity in (public) policy for innovation and standards** Realistic business models for innovation occur when long term perspective, low risk and economic incentives are provided. **Implement past performance system and award on quality instead of price** Awarding contracts on the basis of quality stimulates the performance of private actors and reduces opportunistic behaviour. Combining this with the implementation of a past performance system, incentivises private actors to invest in performance and innovation to remain competitive. In such a way innovation counts competitively. Similarly, for public actors, innovativeness in the sector stimulates public actors to formulate innovative projects.

From the table above, key factors are identified for which the general prerequisite is collaboration and active participation:

1. Striving towards quality in projects changes the dynamics of the market where being innovative needs to be incorporated in the organisational strategies of private actors. Similarly, public actors need to facilitate innovation, standardisation and quality by means of incorporating it in their policies and involving (innovative) actors in pre-competitive stages and stimulate open innovation.
2. The formation of networks, knowledge platforms and databases that facilitate development and sharing of knowledge and innovation.
3. A programme approach is able to function as a platform that facilitates the development of innovations and knowledge while providing long-term goals, across project synergies that align individual and collective interests.
4. Similar projects in the same region across public actors should be bundled together into a portfolio to stimulate productivity, innovation and knowledge development. Additionally, standardising and professionalising the public infrastructure policies gives more grip on the problem and allows for looser regulations that facilitate innovation.

These points resonate with the established need for digitisation of the sector since all of the above mentioned factors are facilitated and enhanced by innovative ICT solutions (see section 3.3).

Box 3. Improving collaboration through the 'Marktvisie'

The 'Marktvisie' is a vision that attempts to restore collaboration between public and private actors, emphasising on trust and respect between actors within the sector and priority on quality instead of costs (Marktvisie, 2016). The collaboration between public and private actors has been disrupted due to increased tensions related to scope creep, financial losses and an unreasonable risk allocation (Marktvisie, 2016). The relationship between public and private actors is plagued by unreasonable contracts where private actors carry high levels of risk against low profit margins (NOS, 2019b). Part of the unreasonable terms originates from the high short-term competition among private actors which incentivises them to propose unrealistic plans with respect to price and risk since traditionally the dominant award criteria for the contract is price not quality (Aanbestedingscafe, nd). Therefore, a new, more collaborative and innovative culture is desired within the sector that improves the relations between actors; towards a network of actors where sharing knowledge is deemed to be beneficial. The table below indicates the transitions that should be realised by the 'Marktvisie'. A success story of the principles of the 'Marktvisie' is project DOEN: a renovation project of the 'Nijkerkerbrug' (a bridge); in which Rijkswaterstaat (a public actor) and the service providers successfully worked together as one team which led to a new approach and shared the knowledge (projectDOEN, n.d.). However, in the past three years the 'Marktvisie' has not been systematically implemented in the sector (RWS & McKinsey, 2019). The transition proposed by the 'Marktvisie' is presented in table 13.

Table 11: Transitions proposed by the 'Marktvisie' (Marktvisie, 2016)

Transitions caused by the 'Marktvisie'	
From	**Towards**
Hierarchical principal-agent relation;	Collaboration through responsibility, complementarity and equality.
Project delivery;	Delivery and unification of assignments*.
Prioritise individual interest;	Thinking, working acting and learning together.
Reactive stance;	Anticipative stance and engaging in dialogue.
Fight relationship;	Excel in working together within reasonable boundary conditions.
Opportunistic behaviour;	Engage in early conversations about risk, information needs and dilemmas.
Power abuse and steering through contracts;	Steering on strengths, attitude and behaviour.
Competitive advantage through knowledge retention;	Competitive advantage though speed and application of knowledge.
Little room for diversity;	Eye for differences and quality and allow customisation.

*Such as the nationwide rehabilitation assignment consisting of multiple diverse projects

4.5 Case summary

In the coming decades the Dutch civil engineering sector as a whole, faces a large-scale and complex rehabilitation assignment. Many ageing bridges and viaducts are nearing their end-of-lifecycle, are subjected to deferred maintenance and subjected to increasing requirements due to changing use conditions and sustainability goals. This increases the demand for rehabilitation projects such that the quality, operation and safety of the Dutch civil infrastructure can be ensured. The complexity of this assignment is related to its scale, the involvement of multiple public and private actors, the uncertainties regarding the state of the bridges and viaducts, lack of collaboration and the low productivity of the sector that currently leads to project cost overruns and time delays. Therefore, for the civil engineering sector to be able to manage this assignment, a productivity increase and a firmer grip on the problem is desired and necessary.

The results of the case study suggests that if digitisation and informatisation efforts within the civil engineering sector are embraced, new developments in ICT could provide the means for the sector as a whole to improve its processes by means of better collaboration, knowledge development and sharing, and more (technological and process) innovations. As a result, the challenges and complexity of the rehabilitation assignment can be addressed and opportunities for standardisation can be identified. Furthermore, reproducible projects, synergies and learning across projects can be facilitated thus improving the sector's productivity. However, implementing the aforementioned changes in the face of a large rehabilitation assignment will need increased collaboration and coordination among actors, and implement long-term inter-organisational thinking that is able to realise change across multiple projects. With regards to these improvements, public actors need to adopt a facilitative role and take initiative; but in the end, this can only be realised through the willingness of both public and private actors to participate in this transition. Therefore, besides technical innovations, appropriate incentives need to be provided through new institutional stimuli and the transition towards a reinvigorated sector should leverage existing initiatives.

4.6 Needs, desires and values from practice

Similar to the previous chapter, the key needs, desires and values are summarised in table 12.

Table 12: Key practical needs, desires and values identified from the case study

	Needs, desires and values from theory
Needs	
	To overcome the large and complex rehabilitation assignment
	To ensure the quality, operation and safety of the Dutch civil infrastructure
	To improve processes to reduce cost overruns and time delays in rehabilitation projects
	To address the challenges and complexity of the rehabilitation assignment
	To adopt a facilitative role and take initiative by public actors
Desires	
	Increase collaboration, productivity and firmer grip on the problem
	Embrace digitisation and informatisation efforts
	Increase knowledge development and sharing, (technological and process) innovations, and standardisation
	Facilitate reproducible projects, synergies and learning across projects
	Towards sector-wide and long-term thinking

	Realise change across multiple projects
	Public and private actors are willing to participate in the transition
	Provide incentives through new institutional stimuli and
	Leverage existing initiatives towards a reinvigorated sector
Values	
	Quality
	Autonomy
	Participation
	Cohesion
	Interaction
	Initiation & transition
	Diffusion & adoption

5. Conceptual Framework Design

A conceptual framework of governance and coordination designed to address the challenges of the rehabilitation assignment

This chapter answers the second sub research question – *can a conceptual framework of governance and coordination be designed to satisfy the identified requirements relevant to the rehabilitation assignment? And how?* – by translating the needs, desires and values from theory and practice into requirements with which a conceptual framework is designed. The framework proposed in this thesis guides the design of comprehensive governance and coordination that is able to address the challenges of the rehabilitation assignment. The framework takes into account the polycentric and project-based nature of the Dutch civil engineering sector and the need for collective action and participation. As such, the framework guides the initiation and development of the necessary structures and processes that facilitate the governance and coordination of a rehabilitation programme throughout its lifecycle.

5.1 Translating needs, desires and values into requirements

As a first step, the theoretical and practical needs, desires and values should be combined. Moreover, the practical needs are those that need to be satisfied as it is relevant to the rehabilitation assignment. The practical desires are suggestive towards a solution space wherein the needs are 'satisfied' if the identified values are adhered to. Furthermore, the practical desires are in turn related to the theoretical needs that in their own right are 'satisfied' by the identified theoretical desires given the theoretical values are adhered to. If a practical solution is to be designed using theoretical insights, then sufficient interplay between theoretical and practical needs, desires and values is required (table 13).

Table 13: Synthesis of practical and theoretical needs, desires and values. The theoretical needs and practical desires are complementary and are synthesised into 'wants' (source"author's own elaboration).

Combined needs, desires and values	
Practical needs	• To overcome the large and complex rehabilitation assignment and address its challenges. • To ensure the quality, operation and safety of the Dutch civil infrastructure. • To improve processes to reduce cost overruns and time delays in rehabilitation projects. • To adopt a facilitative role and take initiative by public actors.
Theoretical needs & practical desires	• To facilitate across-project coordination and interorganisational collaboration: ▪ Increase collaboration, productivity and firmer grip on the problem; ▪ Facilitate reproducible projects, synergies and learning across projects; ▪ Realise change across multiple projects; • To increase productivity and innovation:

    - Embrace digitisation and informatisation efforts;
    - Increase knowledge development and sharing, (technological and process) innovations and standardisation.
- To coordinate and deliberate with participating actors:
    - Towards sector-wide and long-term thinking;
    - Public and private actors are willing to participate in the transition;
    - Provide incentives through new institutional stimuli;
    - Leverage existing initiatives towards a reinvigorated sector.

Theoretical desires

- Implement a programmatic approach for synergies across projects compatible with polycentric systems.
- Implement a new (hybrid) organisational structure.
- Manage multiple projects to achieve higher-order strategic objectives.
- Stimulate productivity and innovation through programmes.
- Adoption and diffuse innovations and knowledge across project and organisational boundaries.
- Establish collective action.
- Maintaining a significant degree of autonomy and decentralised coordination.
- Accomplish a collective mission through participation enabled by ICT.
- Enable innovation (through public procurement) by improving policies and better communication among actors.

Practical & theoretical values

- Quality;
- Autonomy & polycentrism;
- Participation, trust & cohesion;
- Reciprocity & interaction;
- Initiation, transition & adaptability;
- Diffusion & adoption;

5.1.1 Requirements engineering

In this section the needs, desires and values as presented above are translated into requirements such that they are satisfied through design. To begin with, a mission statement of the to-be-designed system is formulated to express needs and desires. Given this mission statement, requirements are derived. Requirements are often of unequal importance, incomplete, inconsistent, interdependent and continuously evolving due to uncertainties (Brazier et al., 2018).

Mission statement

The following mission statement is derived:

"To engage the civil engineering sector in participative processes for the development and operation of a polycentric approach that stimulates collective action and anticipates uncertainties with the aim of addressing the challenges in the rehabilitation assignment more productively"

Functional, behavioural, structural and experiential requirements

The specification of requirements according to the identified theoretical and practical needs, desires and values and mission statement is done according to the proposed method that distinguishes between functional, behavioural, structural and experiential requirements. Table 14 provides a (non-exhaustive) list of the identified requirements that the design must be able to facilitate and satisfy.

Table 14: list of requirements according to the FBSE structure and based on the needs, desires, values and mission identified. (Source: author's own elaboration).

List of requirements	
Functional requirements	
FR 1	The system must address the challenges of the rehabilitation assignment
FR 3	The system must stimulate collective action of public and private actors
FR 4	The system must engage the civil engineering sector in participative processes
FR 5	The system must maintain the autonomy of actors within the polycentric civil engineering sector
FR 6	The system must facilitate cross-project coordination and interorganisational collaboration
FR 7	The system must establish higher-order strategic objectives
FR 8	The system must adapt according to contextual changes
Behavioural requirements	
BR 1	The system must facilitate more diffusion and adoption of knowledge, innovation and standards than current practice
BR 2	The system must realise a reduction in cost overruns and time delays of projects compared to the current practice
BR 3	The system must realise higher-order strategic objectives realise synergies across projects
BR 4	The system must facilitate the shift towards sector-wide and long-term thinking (instead of inter-organisational and short-term)
BR 5	The system must facilitate communication, self-organisation and deliberation among public and private actors
BR 6	The system must implement changes in- and learn from its processes over time
BR 7	The system must facilitate the making joint corrective actions across public and private actors
Structural requirements	
SR 1	The approach's adaptation mechanism must be interoperable with governance, coordination and processes
SR 2	The designed approach should be aligned with existing initiatives
SR 3	The approach's lifecycle should consist of multiple stages
SR 4	The organisational structure must be compatible with the project-based polycentric sector
SR 5	The approach must be enabled by Information & Communications Technologies
SR 6	The approach must contain institutions to structure (social) behaviour
Experiential requirements	
ER 1	The designed approach should realise a sense of trust, empowerment and cohesion
ER 2	Interaction should be reciprocal and fair
ER 3	Transitions and processes should be perceived as reinvigorating for the sector
ER 4	Sense of autonomy
ER 5	(Public & private) Actors should willingly participate

5.1.2 Design considerations

The design put forth in this thesis revolves around the use of programmes and participatory systems to facilitate governance and coordination that are able to stimulate collective action and address the challenges of the rehabilitation assignment. There are no requirement that explicitly mention programmes, yet some requirements are suggestive (FR 7, BR 3) towards programmes and others are directly related to the theoretical concepts associated with programmes and participatory systems. In this thesis, the design space is limited to a specific embodiment of the aforementioned requirements.

In the rehabilitation assignment the social dimension in particular plays a crucial role in the reforming of the civil engineering sector as it requires governance and coordination of a polycentric project-based system. Therefore, the emphasis is put on the process and institutional design perspectives (figure 12) of the three-dimensional engineering perspective (Herder, 2010 p.12).

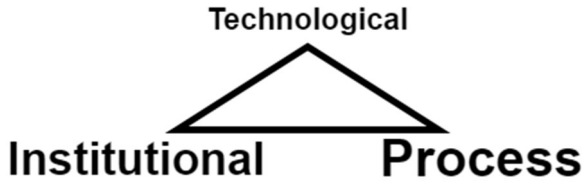

Figure 12: The TIP triangle visualises three-dimensional engineering perspective and emphasises the design focus of the conceptual framework. In this thesis the emphasis is on the institutional and process designs and thus the "institutional" and "process" perspectives of the triangles are of a larger font.

Gall's law for designing complex systems

Taking notice of, and assuming for it to be applicable, Gall's law suggests that:

> *"a complex system that works is invariably found to have evolved from a simple system that worked. The inverse proposition also appears to be true: A complex system designed from scratch never works and cannot be made to work. You have to start over, beginning with a working simple system."* (Gall, 1975 p. 71).

The civil engineering sector has to adapt its governance and coordination to address the challenges of the rehabilitation assignment; a new system ought to be implemented. Preferably in some form of polycentric and participatory programme. However, orchestrating such programmes on a sector-wide scale results in a system of high complexity. Thus, taking Gall's law into consideration, when designing the conceptual framework that in essence attempts to change (parts of) the sociotechnical system (civil engineering sector), it is not of interest to consider in much detail into *what* the system will adapt, on the contrary, it is more suitable to consider *how* such an adaptation can managed and directed according to a coherent framework of governance and coordination – since a complex system evolves from a simple system into a complex system.

Relating it back to the three-dimensional engineering perspective, it complements the argument that the institutional and process perspectives are dominant in this case, whereas the technological perspective is more complementary. The remainder of this chapter will focus on explaining the derived conceptual framework and coarse implementation on the basis of the case study.

5.2 The framework's superstructure

The framework conceived in this thesis proposes a new dynamic approach for orchestrating large (rehabilitation) programmes in polycentric systems by means of enabling collective action throughout the programme's lifecycle. Hence, such programmes involve multiple autonomous yet interdependent public and private actors that act on behalf of their own interests. Four lifecycle stages were identified, namely, the identification, design and planning, delivery and closure stages of the programme. The superstructure outlines and ties together the concepts that need to be taken into account that facilitate the development and execution of the lifecycle (figure 13). More specifically:

- The programme process and its sequential lifecycle stages;
- The coordination of each stage;
- The governance of the programme;
- The implementation and learning in the programme process;
- The adaptation of the programme's process to changing contexts.

The morphology of the framework's superstructure is inspired from the framework for complex system design (Brazier et al., 2018), programme lifecycle (Lycett et al., 2004; Haughey, 2009), and learning and adaptation (van Herk et al., 2012; Rijke et al., 2014).

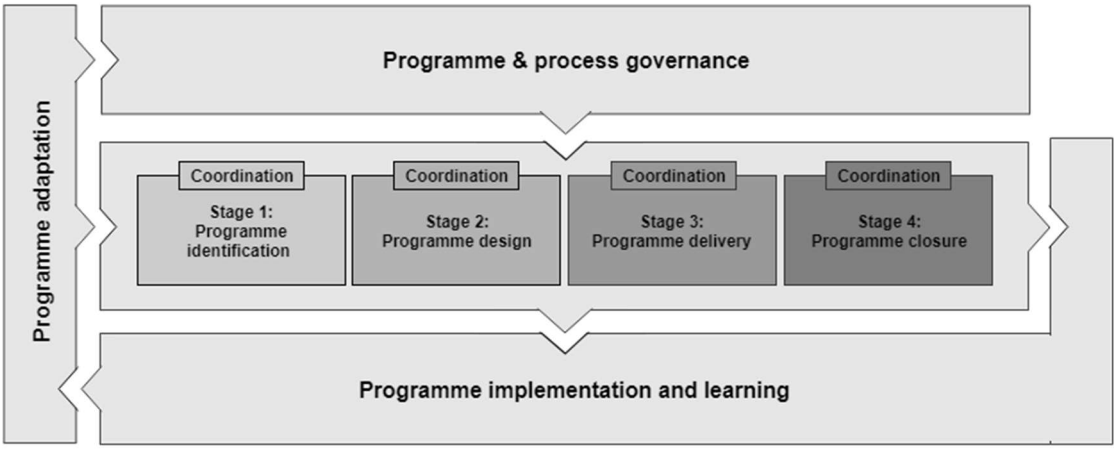

Figure 13: Conceptual framework superstructure consisting of governance, coordination, lifecycle stages and adaptation mechanisms for addressing the challenges of the rehabilitation assignment (Source: Author's own elaboration).

The remainder of section 5.2 is dedicated to providing a more detailed description of the aforementioned concepts.

5.2.1 The programme process and its sequential lifecycle stages

At the core of the framework's superstructure lies the *programme lifecycle*. Each *stage* has its own rationale that contributes to the organisation and execution of the programme in its own right. Thus, all lifecycle stages need to be successfully traversed for the programme to be completed. By suggesting that there is a succession of stages over time, the programme should be seen as a process. The logic of succession, in this case, demands that each preceding stage provides the foundation for the succeeding stage. Thus, each stage consists of the processes that lead to the execution of the next stage in the programme.

The programme requires the collaboration and negotiation between the involved actors in multiple decision-making rounds. The four stages have their own rationale but the entire programme lifecycle

should be built around the principles of openness, protection of core values, progress and substance. These principles are fundamental for a good process design. The rationale of each programme stage is based on the activities that it should facilitate. Hence, the nature of the decisions to be made in the programme process are dependent on the nature of these activities (table 15).

Table 15: Four programme lifecycle stages adopted from Haughey (2009); Lycett et al. (2004); Rijke et al. (2014) and supplemented with information from previous sections.

Four lifecycle stages of the programme process	
Stage	**Description**
1 programme identification	At this stage the programme is decided on the basis of the *strategy and objectives of the multi-actor network*. Within this stage the high level *vision*, *strategy*, *aims & objectives* and *scope* are defined. The result is to derive a high-level programme description with clearly delineated higher-order strategic objectives through engaging with a relatively small multi-actor network willing to take initiative – i.e. a programme coalition consisting – that is able to 'set the agenda' and determine the programme process governance structures.
2 programme design	At this stage the programme coaltion shifts towards the *design process*. Within this process, defining clear *objectives* and *expectations,* the institutional and tdchnological designs are constructed. Additonally the process should define an *approach* and the *definition of roles* across the different actors that are involved. The aim of the design process is to *establish the communication channels* and the respective enabling ICT architecture that will facilitate the programme delivery process. Furthermore, the *organisational structures* and *actor roles* should be defined that governs and coordinates the interactions between projects and actors within the delivery process. Furthermore, the programme *planning* should facilitate the progression of the programme delivery process through *defining and allocating programme resources* to early projects whilst *identifying requirements* for later projects.
3 programme delivery	In th the stage, the programme design and planning is executed. The diverse projects of the programme are executed by the participating actors and according to the rationale provided in the previous stages. Here, the programme process carries the responsibilities to *monitor and report progress* to the in-place process governance system that ensures the *high-level strategic objective and synergies* are maintained. These tasks are oriented toward *maintaining the alignment* between programme objectives and programme strategy, and the overall *project productivity*.
4 Programme closure	is the last stage in which the programme is terminated as a consequence of the *successful completion of all projects* and *meeting the objectives* set in the early stages. In this stage the programme is *evaluated and reviewed* on the basis of performance such that it might be used as a model for other programmes.

5.2.2 The coordination of each stage

The activities within each stage need to be coordinated accordingly. Coordination of a stage entails the organisation and management of system elements – such as actors, information, resources, projects and activities – such that those system elements and activities are able to effectively work together.

Naturally, since each stage consists of different processes and activities, the focus of coordination will vary significantly with different incentives, motivations and emotions at play (Malone & Crowston, 1994) that determine the appropriate coordination strategies for each stage (Brazier et al., 2018). Table 16 sets the focus of coordination according to the rationale of each stage on the basis of the needs and desires derived from the previous chapters.

Table 16: Focus points of coordination according to the rationale of each stage of the programme lifecycle. The 'incentives, motivation and purpose' structure is adopted from Malone & Crowston (1994), information obtained from own research (Author's own elaboration).

	Coordination foci according to the rationale of each stage		
	Incentives	**Motivations**	**Emotions**
Stage 1	Include own issues in setting the agenda. Protect core values.	Align collective interest with individual interest.	Building trust (trust) and level playing field (equality).
Stage 2	Setting technical standards.	Increase influence in end design.	Co-created design (cohesion), protect core values (safety).
Stage 3	Financial, performance and status incentives.	Facilitate autonomy and across projects synergies.	Need for collective action (cohesion), fear for opportunism (fear).
Stage 4	Publicity and relationship building.	Better exposure.	Finishing what you started (determination).

In the first stage coordination entails the guiding of the deliberation processes of programme identification – i.e. coordinating negotiation and decision-making (van Bueren et al., 2003; E. Ostrom, 2008; de Bruijn et al., 2010). Whereas in the second stage, coordination shifts towards the coordination of design-team formation and programme design where any impasses that arise are resolved through negotiation and consensus; here the coordination strategy of the previous stage still has a role to play in decision-making while the coordination of design should revolve around using groupware and common interfaces. The coordination of the third stage is dependent on the (design) decisions made in the first and second stages. However, the coordination of the delivery stage should facilitate synergies across projects and collective action among actors: this needs to be facilitated both institutionally and technologically (Kunneke, 2013). Table 17 summarises the identified coordination methods of each stage.

Table 17: Overview of identified coordination methods for each stage respectively (Source: Author's own elaboration)

Stage	**Proposed coordination methods**
1 programme identification	Management of a political process in which core participants engage in negotiations to define the vision, aims, objectives and scope of the programme according to their individual strategies and objectives. A democratically appointed process manager can guide the process on the basis of the process design (de Bruijn et al., 2010).

2 programme design	Continuation of the previously suggested process management approach for the participatory design and planning of the programme (de Bruijn et al., 2010). Coordination through a well defined design process and interface management between design teams. Coordination mechanisms such as process standardisation, groupware and shared resources can facilitate decentralised action in the design teams (Brazier et al., 2018). Goal of coordination is establishing a 'virtual' programme organisation (Evaristo & Fenema, 1999) both technically and institutionally through characterising the different kinds of dependencies and identifying different kinds of coordination mechanisms that are able to manage those dependencies (Malone & Crowston, 1994 p.5-6; Kunneke, 2013).
3 programme delivery	Coordination through utilsing the technological and institutional systems established in the previous stages. These systems should (at least) facilitate: i) the decentral coordination of sequential and concurring projects creating synergetic effects, ii) the self-organisation of actors to engage in collective action – i.e. sharing of innovations, knowledge and information, ii) shared situational awareness. The coordination mechanisms are based on incentives, commonly agreed-upon standards and shared resources – e.g. ICT systems and standardised processes, documentation and data – depending on the institutional & technical designs.
4 Programme closure	In this stage the programme is completed and the higher-order strategic objectives are met. *Process management* may be used to negotiate a final document (codified knowledge) whilst the decentralised coordination of information to supplement the evaluation and review of the programme.

Finally, although participatory systems are characterised by decentralised coordination, in stages where consensus is required through negotiation and decision-making needs to be facilitated (for instance in the programme identification stage), central coordination might be an effective mechanism to guide the negotiation process (i.e. by appointing a process manager) (de Bruijn et al., 2010). Similarly, in second stage a mix of central and decentral coordination might be desired in the design process where central coordination is used within design teams and decentral coordination is used across design teams.

5.2.3 The governance of the programme

Governance refers to the establishment, implementation and monitoring of policies and the provision of the programme's organisational structure. Programme & process governance focuses on the coordination of the programme lifecycle as a whole and the interfaces with its environment. In contrast to the traditionally hierarchical governance of Programme Management Offices, this thesis proposes, a fundamentally different approach to governance in programmes. This is referred to as horizontal or networked governance where policy is made in interactive processes (Jones et al., 1997; Klijn & Koppenjan, 2000); and thus, stimulating collective action (E. Ostrom, 2008). Moreover, this approach is based on the premise of self-organising networks, consisting of many actors that are interdependent to one another, forming through complex cooperative practices that is able to deal with disputes (such as cost and benefits distribution) (Klijn & Koppenjan, 2000). With interdependent implying that each actor possesses resources that are required by other actors in the network. Such approaches are facilitated in hybrid organisational structures.

This approach to governance is more compatible with polycentric systems as it focuses on the interdependent (instead of hierarchical) relationships among the programme's public and private actors. The choice of organisational structure is not an either-or decision, rather, more complexly combinations of organisational structures may emerge over time (Menard, 2012). For instance, some actor(s) may establish a more prominent role on the basis of proportional benefits to costs (Jones et al., 1997; E. Ostrom, 2008). Table 18 compares the traditional approach to the polycentric approach to governance based on the information in chapter 3.

Table 18: Comparison of governance characteristics between the traditional approach and approach presented in this thesis (Source: Author's own elaboration)

Comparison of properties associated with two approaches to governance		
	Traditional	**Polycentric**
Organisational structure	Hierarchical	Hybrid
Topology	Centralised	Networked or mixed
Programme Management Office	Autocratic	Democratic
Policy establishment & decision-making	Authoritative	Self-organised & negotiated
Monitoring	Supervised; reactive	Shared situational awareness; proactive
Flexibility	Robust	Adaptive

Furthermore, the evolving character of the programme lifecycle and the diverging rationale of its stages and respective coordination strategies, programme & process governance should be able to cope with the breadth of these activities and the uncertainty of these stages in the earlier stages of the process and thus be able to adapt as the programme progresses accordingly.

5.2.5 Implementation and learning in the programme process

Implementation and learning is effectuated as the programme lifecycle is executed. Through the implementation of the programme process, its constituent stages, activities and decision-making rounds, the governance, coordination and stages are subjected to (positive and negative) feedback – e.g. through assessments and testing (van Herk et al., 2012; Brazier et al., 2018). This process is considered as learning. Learning effects can influence multiple elements in the superstructure – for example, learning in stages can invoke changes in coordination and governance.

5.2.6 Adaptation of the programme's process to changing contexts

Adaptation refers to the process of altering the programme to changing contexts (Lycett et al., 2004; Rijke et al., 2014) and is the mechanism that implements learning outcomes – i.e. translation of lessons learnt into practical change. As can be seen figure 13, all elements of the programme's superstructure (lifecycle stages, coordination and governance) are subjected to adaptation.

5.3 Programme process and design process

In the framework's superstructure, the term programme process is used to describe the programme's progression over time as a consequence of multi-actor interactions. In essence this process lasts across the entirity programme's lifecycle, however, the rationale of the first and second stages rely the most on a process design. This is because initiation and design need extensive deliberation to resolve existing collective action problems and momentum needs to be built and maintained.

After the vision, strategy, aims, objectives and scope of the programme are set in first stage (programme identification), the process enters the second stage (programme design) wherein necessary design choices need to be made and executed. Hence, besides the aforementioned process (relevant for the planning), there is also a need for a design process. The design process facilitates the design of the institutional and technological structures and processes delivery stage. In the remainder of section 5.3, the process design and design process designs are explicated. The process design and design process are in part based on Groenewege & Koppenjan, (2005); see Appendix D.

5.3.1 Programme process design: creating momentum and facilitating collective action

In the process design the first four rounds are explicated (round 1, round 2.1, round 2.2 and round 3) yet any 'n' number of rounds may exist in the programme lifecycle depending on the design choices, needs and nature of the programme and its participants. A round as specified in this thesis has its origins from process management (van Bueren et al., 2003; de Bruijn et al., 2010). The need for rounds within the programme lifecycle lies within the fact that the rehabilitation programme takes place in a polycentric system consisting of autonomous yet interdependent actors. d they form networks in which those actors need to participate in the programme process and engage in decision-making processes to create a shared and negotiated understanding of the purpose and embodiment of the programme.

Decision-making in multi-actor networks is not particularly easy; especially if there are conflicting interests and actors display strategic behaviour (de Bruijn et al., 2010 p.16-17). Thus, rounds are necessary within the programme process since they facilitate such decision-making processes and are able to stimulate collective action and break impasses (van Bueren et al., 2003; de Bruijn et al., p.16-17). Therefore, it would be a naïve thought to exclude rounds in this process since momentum needs to be created and maintained and decision-making processes need to be facilitated over the course of the programme lifecycle. According to de Bruijn et al. (2010 p. 43) a good process design leverages the following design principles that guide the process: openness, protection of core values, progress and substance. These are covered in detail in Appendix A5.

The 'main' process is initiated in the first stage and lasts untill the end of the second stage. However, since the programme stages are ongoing as they are susceptible to adaptation and given that the programme is in its essence a multi-actor network facilitated by technology, the process should be kept going during the whole lifecycle – for example as a facilitator for self-organisation, further deliberation or serving as a conflict resolution mechanism. Table 21 describes the initial four rounds defined in the process model based on the need for building momentum and the programme stages presented in the previous section (table 13).

Table 19: Four initial rounds and an example of follow-up rounds (n-th round). These rounds are based on the need for momentum and the programme lifecycle. (Source: Author's own elaboration)

Rounds within the programme process			
Round	**When?**	**Description**	**Size of the network**
1	Beginning stage 1	Core coalition of diverse and intrinsically motivated actors engage in the decision-making process that determines the programme identification stage. Furthermore, the core coalition is responsible for initiating the process design, governance and coordination, and the execution of the first stage (programme identification).	Small
2.1	End stage 1 towards beginning stage 2	The process is opened up to actors that are willing to participate and provide input in finalising the first stage and initiate the second stage (programme design).	Medium
2.2	Beginning stage 2	The design process is initiated and the programme process is closed to new entrants. The decision-making revolves around the technological and institutional design of the programme delivery in which public and private actors contribute within design teams.	Medium
3	End stage 2 towards beginning stage 3	At the end of the design process, the programme process is reopened to new entrants that wish to participate. Although the design is largely finalised, pilot projects still function as an improvement mechanism and initiate the delivery stage. In the third stage (programme delivery) the programme is operational and decision-making occurs on the basis of self-organisation constrained by the technological and institutional design.	Large
'n'	Variable	Example of a n'th round: a dispute resolution between two or more actors within the mutli-actor network, the adaptation of the programme according to changing contexts, decision-making around the programme closure etc.	Variable

5.3.2 Design process: facilitating cohesion between institutional and technological design

In the preceding section the programme's process design is introduced. The aim of this section is to dive deeper into the *design process* that leads to the programme delivery stage. More specifically, design objective is to derive the programme's sociotechnical composition – i.e. the conceptualise the institutional and technological characteristics – that make up the programme delivery stage such that its operationalisation is according in accordance with the outputs of the programme identification stage. Thus, the concepts presented in this section are associated with the second stage programme's lifecycle. To be more precise on what is meant with institutional and technological design, we adhere to the following description (Groenewege & Koppenjan, 2005):

- *Institutions*: deployed organisational arrangements and the rules-in-use that structure interactions among participating actors and technologies.

- *Technology*: deployed technologies, such as the Information and Communication Technologies (ICT) that facilitate the programme's processes and the technical characteristics of the rehabilitation assignment and civil engineering structures for which the programme aims to create synergies (in this case to share innovations);

The objective in this section is not to exhaustively design the technological and institutional dimensions of the programme delivery stage, but to provide a high-level representation on how these dimensions interrelate and come together to form a preliminary programme design that satisfies the inputs of the previous programme lifecycle stage.

Alignment: institutional and technological coherence on multiple levels of abstraction

When designing large sociotechnical systems, the coherence between the technological and institutional design must be facilitated since they are highly interdependent to one another. That is to say, without technological and institutional coherence, the functioning of the programme in the delivery stage would not coincide with the expected system performance (Kunneke, 2009). Simply put, technology and institutions are fundamentally embedded. If the coherence between the technological and institutional designs does not suffice, the programme will not be able to meet its objectives and expectations. Therefore, in the quest of coherence, complex sociotechnical systems such as the one under study – i.e. the rehabilitation programme – have multiple levels of abstraction at which technological and institutional alignment needs to be realised. Kunneke (2013) refers to the design process of achieving this coherence as alignment and provides the alignment perspective as means to achieve this.

Figure 14 depicts the alignment perspective framework in which the technological and institutional designs of a system are aligned on multiple levels of abstraction. The presented framework relates the alignment perspective to framework's superstructure of the programme process described in section 5.3. The premise of the approach is to align technology with institutions such that the system performance of the rehabilitation programme complies with the objectives and expectations of the participants determined in the *first stage* of the programme lifecycle. These levels of abstraction interact with one another according to *critical functions* of the programme, imposing requirements that must be technologically and institutionally organised within the system (Menard, 2018). The purposes of the three abstraction levels are described as:

- *Level 1:* determining the *technological architecture & general rules* in which the alignment establishes the access of participants and the general rules of the programme;
- *Level 2:* determining the *technical design characteristics & programme arrangements* in which the alignment establishes the governance of the programme with respect to the programme's technical design and arrangements;
- *Level 3:* determining O*peration & Participation* in which the alignment establishes the coordination of activities between participating actors necessary to facilitate operation of the programme.

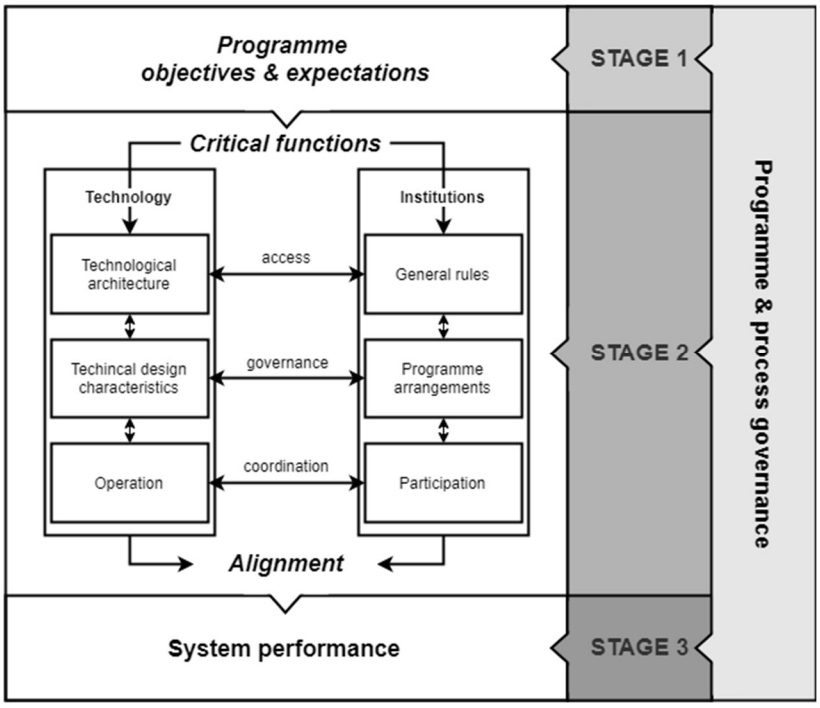

Figure 14: Based on the alignment perspective for designing sociotechnical systems adopted from Kunneke (2013) and Menard (2018). This figure displays the design process of the programme. The design is based on satisfying the critical functions; it consists of technological and institutional systems represented at multiple levels of abstraction. It is important for the technological and institutional systems to be aligned with one another into a coherent design such that the programme's objectives and expectations are met in the system performance.

Design process for programme design

In the second stage of the programme lifecycle, the design-teams engage in the conceptualisation of programme design and the design execution. The design execution involves constructing the technical components of the programme in accordance with the design but are not covered in this thesis. On the basis of the logic presented in the framework visualised in figure 14, the design conceptualisation should start from highest level of abstraction and traverse down to the lower levels of abstraction. The aim is to coordinate the institutional and technological designs by means of their alignment such that they are able to support the critical functions of the programme. The critical functions of the programme, which are derived from the programme objectives and expectations (defined in the first stage of the programme lifecycle), are characterised as critical because they need to be technologically and institutionally organised within the programme to ensure the system performance of the programme (Kunneke, 2009; Kunneke et al., 2010). The specification of those functions is dependent on the scope and context of the programme and provide the initial '*shape'* of the programme's design. In addition, the choice of alignment between the technological and institutional designs further delineates the means by which the critical functions are embodied. The critical functions are identified as system control, capacity management, interconnection and interoperability (Kunneke, 2013). Moreover, we differentiate between three types of alignment, each responsible for the coherence of technological and institutional designs at a specific level of abstraction. Therefore, we shall explicate what is meant with each type of alignment and how it affects the programme's design.

Alignment type 1: accessibly of the programme in the delivery stage

This abstraction level revolves around the definition of technological architecture and general rules on the basis of the critical technical functions. In the process of aligning those two perspectives, we are

looking at ways to determine the access to the programme – i.e. what actors can participate in the programme. We can distinguish between two extremes, closed access and open access. The chosen accessibility '*threshold*' to the programme (specific agreements for who is able to enter the programme) has an impact on the institutional and technological coordination of the critical functions (Kunneke, 2013). For instance, if the programme's accessibility threshold is low, the technological architecture and general rules must be able to facilitate the potentially large influx of participants thus constraining the programme's design.

Alignment type 2: governance structures and processes of the delivery stage

The higher abstraction level have further constrained the programme's design possibilities. This level is dedicated to determining the technical design characteristics and programme arrangements that are able to support the critical functions at a higher resolution. Consequently, the governance is responsible for ensuring that the technical design characteristics and programme arrangements cohere such that the critical functions are facilitated. The goal here is to set out the technological and institutional structures with which programme is operationalised in the next design step. Therefore, the alignment at this level of abstraction – i.e. establishing coherence between technical design characteristics and programme arrangements – constitutes the governance of the programme delivery.

In the framework proposed in this thesis, the governance in the delivery phase is part of the programme & process governance. The programme & process governance is responsible for aligning the lifecycle stages with one another and establishes the organisational structure and monitors the implementation of policies during the programme lifecycle. Therefore, the activities of programme & process governance includes the definition of the hybrid organisational structure responsible for the operationalisation of governance in the delivery stage.

Alignment type 3: coordination structures and processes of the delivery stage

Given the shape that the programme has acquired by specifying the higher levels of abstraction, at this point the interactions between participating actors are structured on the basis of the programme's operational characteristics and participation needs of the programme such that the critical functions are managed appropriately. This form of alignment is referred to as coordination. The objective is to characterise the different kinds of dependencies and identifying (technical and institional) coordination mechanisms and structures that are able to manage those dependencies respectively.

Overview of programme design process

In theory, by taking the aforementioned into account, a coherent sociotechnical design of the rehabilitation programme is conceived that ensures the system performance according to the established objectives and expectations. More specifically, a design that translates objectives and expectations of the programme's performance into critical functions that need to be actively managed both institutionally and technologically. This coordination must, in turn, be embodied and facilitated across three abstraction levels that determine the access, governance and coordination of the programme respectively. The design choices at each level of abstraction are dependent the previous abstraction level (or design step), and on the institutional and technological requirements. Table 20 provides an overview of these design-choices and the layout should be used as a framework for the programme delivery design from a governance and coordination perspective.

Table 20: Overview of design-choices for the programme delivery stage. Based the Author's own elaboration, the programme lifecycle (section 5.3 and the alignment perspective adopted from Kunneke (2013).

Overview of design-choices for the programme delivery stage		
Objectives		**Expectations**
List objectives of the programme as specified in the first stage of the programme (e.g. collective action and innovation diffusion)		List expected performance of the programme (e.g. participants need to be able to self-organise and exchange knowledge)
Critical functions		
The functions that facilitate the objectives and expectations but need to be institutionally and technologically organised within the programme: on the basis of interoperation (elements need to fit together), interconnection (connection between elements), capacity management (balance of capacity in the system) and system control (operation according to certain requirements)		
Technology	**Alignment**	**Institutions**
Technological architecture Feasible technological system and rationale that is able to facilitate the critical functions of the programme.	***Access*** The degree of accessibility to the programme for actors that wish to participate.	***General rules*** Involves the general rules of the programme for which access and technology are facilitated, formal rules (laws), culture & norms.
Tech. design characteristics The technical and process characteristics of the programme.	***Governance*** The appropriate governance structure and processes that supports the operationalisation and monitoring of the programme.	***Programme arrangements*** Specific requirements and rules of the programme which determine the policies/guidelines (such as incentives and monitoring) that facilitate the different types of interactions between the actors.
Operation (immaterial) resources and detailed project processes.	***Coordination*** Coordination mechanisms that facilitates the interaction between actors.	***Participation*** Organisational characteristics of actors, interdependencies, self-organisation and collective action of actors.

5.4 Implementation of the conceptual framework

The previous sections outlined the conceptual framework proposed in this thesis. In this section the conceptual framework is covered in greater detail by reducing the level of abstraction and providing suggestions for implementation where possible. The case information used to implement the conceptual framework. Furthermore, the implementation is limited to the first and second stages. The deliverables of this section are a process design and a high-level conceptual design of the programme delivery stage.

5.4.1 Combined representation of the programme process design and superstructure

The process design explicitly covers the first, second and beginning of the third stage of the programme lifecycle. Figure 15 depicts a detailed representation of process design (section 5.4) as part of the framework's superstructure (section 5.3). More specifically, the intermediate objectives of the rounds

in accordance with the programme lifecycle stages, the dominant coordination principles within the rounds on the basis of the stage's rationale, and the establishment of programme process governance throughout the initial two stages of the programme lifecycle. Furthermore, the conceptualisation specifies the dominant design principles of each round within the programme process. A programme process design, as mentioned in section 5.4 and appendix B5, is based on the principles of openness, protection of core values, progress and substance.

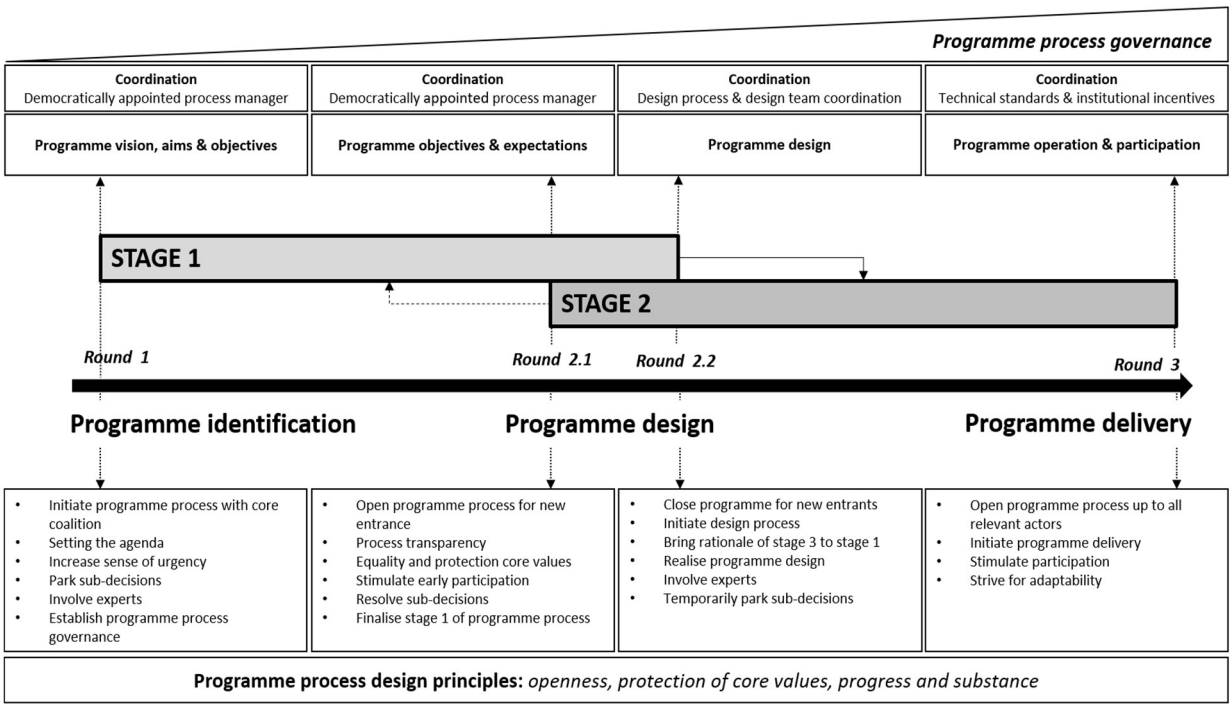

Figure 15: Detailed process design for the rehabilitation programme in relation to other elements of the framework's superstructure. (Author's own deliberation)

5.4.2 Programme & process governance

The programme & process governance is initiated in the first round (round 1) of the process design and coincides with the first stage. The process design guides the development of governance structures and processes by means of network governance (Klijn & Koppenjan, 2000). This implies that all policies incorporated at the end of for instance stage two *need not* be implemented at the start of the first stage. In this regard, the programme & process governance is adaptive to the context of the programme lifecycle stage it is in and 'evolves' into maturity. Hence, the programme process governance is visualised as a slope (figure 15). The aim of governance is to establish and monitor the policies that ensure the programme's lifecycle is executed through structures and processes.

Furthermore, the governance (organisational) structure of stage 3 (which aligns the technical design characteristics with the programme arrangements) is developed in the design process of stage 2 and effectuated in stage 3 accordingly. Since a hybrid organisational structure is proposed (Menard, 2012), some third-party coordination, such as a 'lighter' version Programme Management Office staffed with democratically appointed actors, that monitors the implementation of policies derived by the policy network can be beneficial depending on the design-choices made in earlier stages of the programme's lifecycle. However, given that the rehabilitation programme should be participatory, it should not directly influence the self-organisation of actors. A nice example in the civil engineering sector is 'de Bouwcampus' on the TU Delft campus: although 'de Bouwcampus' is a participatory (physical) platform in which public and private actors in the construction sector can engage in pre-competitive

collaboration, it has a directorate and management that is responsible for the short-, medium- and long-term operation of the platform – i.e. keeps the platform 'up and running' without interfering with the content of the activities on the platform (de Bouwcampus, n.d.).

5.4.4 Process design for Stage 1: programme identification

Description of vision, aims and objectives

At this stage, the multi-actor network is considered as the initiating public and private actors that are innovative and technologically advanced with a high sense of urgency. In short, the strategy of the multi-actor network is to reform the civil engineering sector into a technologically developed and long-term oriented sector. The objectives of the multi-actor network are to engage the sector, stimulate innovation and knowledge development through institutional renewal and collaboration. The underlying motivation is the large and complex upcoming rehabilitation assignment of bridges and viaducts that is subjected to many uncertainties and considered as too expensive. On the basis of the case information the following vision, aims and objectives are derived (table 21).

Table 21: Vision, aims and objectives as determined in stage 1 (author's elaboration based on chapter 4)

Determining vision, aims and objectives of the rehabilitation programme	
	Description
Vision	Organise a programme that is able to increase the productivity and grip on the problem such that rehabilitation assignment of bridges and viaducts becomes technically and economically feasible.
Aims	Realise a Institutional renewal and increased sense of urgency, improve the sector's situational awareness and competence, change the sector's culture, reform the sector's organisation.
Objectives	Incentivise innovation, standardisation, collaboration (among public actors, among private actors, and public and private actors), development and sharing knowledge across organisational and project boundaries. Facilitate collective action.

Round 1: programme initiation

In round 1 a core coalition is formed consisting of selective actors from both public and private domains characterised by a high sense of urgency who are able to initiate the rehabilitation programme of bridges and viaducts by setting the agenda. The first round is characterised by a low initial number of participating but intrinsically motivated actors. However, in this round, the participating actors actively represent the different and sometimes conflicting interests within the civil engineering sector. Therefore, the core coalition engages in negotiation processes in which the obstacles of the civil engineering sector, metaphorically, are put on the table.

It is in this round that the programme's 'character' is defined and the sense of urgency is increased. The ambition of this round is to realise the rationale of the first stage and bring up the main issues that need to be negotiated while protecting the core values of the actors. Broadly distinguishing between the core values of public and private actors. Public actors value rehabilitation projects to be innovatively executed without cost overruns and time delays and improve their asset management activities, whereas private actors value profitability and income continuity of projects and innovative ideas. If any impasses occur on sub-decisions, then these should be moved onto the agenda of the next round.

Given these negotiations, the identification of the programme is initiated where the programme's vision, aims and objectives are established. A high degree of actor diversity implies that the vision, aims, objectives and scope of the programme contain sufficient substance for the second stage. Involving experts from both academia, government and business for advice can help set the If not, this will result in iterative deliberation that stalls the effective implementation of the programme delivery stage. Subsequently, the core coalition is appointed the crucial task to establish the foundations of the programme process governance.

Public actors

According to the case study, Rijkswaterstaat, province Noord-Holland and province Overijssel are public actors that have actively participated in the core coalition of Bouwagenda roadmap 1. They are considered as progressive and professional public actors with an increased sense of urgency and are thus suitable public actors to initiate the programme. Other public actors such as the municipalities of Amsterdam and Rotterdam have shown an increased sense of urgency and could be included such that a good representation of all government layers is established. On a final note, ProRail would also be an interesting candidate to include in the first round due to their size and their characteristic of being a quasi-government agency.

Private actors

The participation of private actors such that the interests of the market are represented in the initiation phase is of importance. More specifically, key private actors with a high sense of urgency and technologically advanced and innovative service providers should be involved at an early stage to set standards within the sector. A diverse set of service providers representing engineering consultancies, contractors and suppliers will enhance the quality of the first stage. Furthermore, including actors from other industries is also mentioned as a strategy; these actors, being outsiders, introduce novel ideas and new ways of thinking to the sector (EIB, 2017).

Other stakeholders

The DigiDealGO, BTIC, de Bouwagenda, and Marktvisie initiatives demonstrated that involving associations and knowledge institutes are important actors to include. Associations represent the interests of a large group of actors (both public and private) and have a direct communications channel towards these actors. On the other hand, knowledge institutes such as TNO and universities such as the four technical universities of the Netherlands are respected institutes and a valuable source for expert and theoretical knowledge and can provide high-end research in both real-life, virtual and laboratory contexts.

Round 2.1: from initiative to action

Round 1 is finalised when a consensus is reached by the core coalition that describes the vision, aims and objectives of the rehabilitation programme; consequently, round 2.1 is initiated. The transition between rounds happens near the end of the first stage of the programme and at the beginning of the second stage of the programme. In round 2.1, the programme process is opened up where relevant and interested actors that have gained an increased sense of urgency due to the impetus generated by round 1 are invited to formally join and participate in the programme. Actors can also be incentivised to participate by emphasising on why it is beneficial to participate in an early stage – namely, actors are able exert influence on the agenda and decisions. However, transparency and protecting core values is important to the process' viability to ensure the feeling of integrity (De Bruijn et al., 2010).

In this round, the first stage is finalised where any impasses on sub-decisions of round 1 are resolved and necessary changes are incorporated into the high level vision, aims, objectives and scope of the programme. This results in clear objectives and expectations of the programme.

Delineating programme objectives and expectations

For the Dutch civil engineering sector to be able to deal with the scale and complexity of the rehabilitation assignment an increase of productivity and competence is necessary. The general perception is that a more innovative and collaborative sector is required that is able to distance itself from the current tendencies of short-term competition and opportunism, and consequently stimulate the (co-)investments in innovation and knowledge development and sharing. A leap towards a digitised and informatised sector is able to facilitate this transition. Digital technologies (such as Building Information Modelling, computation, the internet of things, sensor technologies etc.) provides new opportunities for process and technological innovation, knowledge development and sharing and collaboration between organisations and across projects. Therefore, given the increased attention to digitisation within the sector, the programme should reap the benefits such that innovative solutions are scaled up and implemented across projects. Just as programmes are facilitators of innovation, so are digital technologies. Combining the information pieces of the case study, the combination of programmes and Information and Communication Technologies should improve the sector's participation, productivity and competence. Based on these principles, the objectives and expected system performance of the programme's users is formulated (table 22).

Table 22: Suggested objectives and expectations for the implementation of a rehabilitation programme

Suggested objectives and expectations	
Objectives	**Expectations**
Collective action	Actors are able to self-organise
Improve overall rehabilitation project performance and success	Knowledge and innovations are developed, diffused and adopted across rehabilitation projects and actors

Coordination of stage 1

The first stage of the programme is to (democratically, i.e. by consensus) appoint a process manager that is able to guide the process – such as a well-respected and highly experienced individual within the sector supported by a team of experts (De Bruijn et al., 2010; CoBouw, 2019c). The coordination strategy of the process manager is to stimulate participation by creating an environment based on equality and mutual trust between actors and manage the process such that consensus is achieved on issues with initially conflicting interests.

5.4.5 Process design for Stage 2: programme design and planning

The second stage shifts towards the design of the programme delivery stage in line with the objectives and expectations set in the first stage (more specifically in round 2.1) of the rehabilitation programme. After the objectives and expectations are set by the broader programme coalition, round 2.2 is initiated where the programme process is closed to new entrants and the design process is initiated. The approach is oriented toward designing the delivery stage of the programme in which the programme is operationalised. In chapter 3, the design process proposes the use of the alignment perspective (as proposed in the previous section) through which the technological and institutional designs are established (this will be covered in the next section).

Round 2.2

In round 2.2 the design process is initiated for which and the programme design is formalised according to a technical and institutional design. This formal design embodies the critical functions that represent the objectives and expectations of the programme. The design of the programme should be specified according to roles, objectives and approach as well as the communication channels that facilitate the interaction within the rehabilitation programme. It is essential to compose design teams of competent actors to whom relevant tasks are allocated. This thesis proposes a participatory design approach consisting of design teams that coordinate with one another to establish all of the necessary design components that constitute the complete programme design.

The core coalition can take point and facilitate the design process by laying out an initial plan, provide the necessary resources and involve experts to initiate the design process. For instance, supplementing a green paper of the programme's technological architecture and programme arrangements. The core coalition would consist of national, regional and local asset managers and innovative and technologically advanced service providers (contractors, engineering consultancies and suppliers of all business sizes). The benefit of this composition is the ability set sector standards and provide knowledge that contributes to the programme's design. Also, given that the core coalition has the highest sense of urgency, the core coalition can stimulate the progress by rallying the other participating actors.

In turn, coordination and the programme process governance can stimulate early participation by setting individual issues on the agenda such that they can potentially be included in the programme design. For example, amending specific arrangements or technical design characteristics of the programme and supplying pilot projects for learning purposes, innovation and standardisation. A good inspiration for this process is how the DigiDealGO initiative attracts pilot projects from both public and private perspectives (DigiDealGO, 2019c).

Coordination of stage 2

The coordination of stage 1 is continued in the sense that the programme process needs to be facilitated, however, as the programme becomes more mature, these functions are incorporated in the governance structures. Furthermore, the design process needs to be coordinated accordingly. A programme's design involves technological and institutional components at multiple abstraction levels that need to be designed and incorporated in the complete design. In the design process (round 2.2) the coalition consists of the initial core coalition and actors that decided to join the programme process in round 2.1. This broader coalition will engage in the design process of the programme in design teams consisting of competent actors. These teams need to coordinate with one another. A standardised design process and interfaces, groupware and shared resources (such as information, a common physical meeting place) are able to coordinate design activities.

5.4.6 The design process

As aforementioned, round 2.2 initiates the design process that is part of the second stage of the programme lifecycle. The goal of the design process is to provide a comprehensive programme design consisting of coherent technological and institutional designs on the basis of the programme's critical functions. Those are the programme's functions that need technological and institutional organisation in order to realise the expected system performance. The specification of those critical functions are derived from the programme objectives and expectations supplied by round 2.1 of the programme process. From these functions the programme's design can be derived from the alignment perspective in accordance with the sector's technological and institutional characteristics.

For instance, the formal (laws and regulations) and informal rules (culture and norms) of the civil engineering sector need to be taken into account. Of course, the intention is to overcome the sector's obstacles, change the sector's culture and reform the sector's organisation. Thus, institutional renewal is required which will inevitably deviate from the current formal and informal rules. An assumption here is that it is important to be able to identify the divergence points and ensure that the change is not *'too radical'*. Similarly, the technological characteristics such as current project processes and standards – that are embedded within sector and difficult to change – should be taken into consideration within the programme's design.

Determine accessibility threshold: technological architecture and general rules

In this thesis the rehabilitation programme is defined as a participatory system consisting of social, communications and technical layers enabled by Information and Communication Technologies. The digitisation and informatisation transition of the civil engineering sector aligns nicely with the conceptualisation of the rehabilitation programme as a participatory system. Using a digital platform as the technological architecture should be at the core of the rehabilitation programme that is able to facilitate the inter-organisational and cross-project processes – platforms can offer multiple digital products and services. The projects that are referred to here are related to the inspection, maintenance, renovation and replacement of bridges and viaducts. This concept matches with the idea of developing networks and databases that facilitate the development and sharing of knowledge across organisational boundaries leading to network effects; for example complementary information and knowledge related to sufficiently similar bridges and viaducts that enhances project processes. Furthermore, digital platforms facilitate self-organisation as they facilitate the interconnection between the participating actors and resources. Creating such a system of networked systems requires that the systems deployed across the participating actors are interoperable.

In the programme delivery stage of the programme lifecycle, the intention is to attract *all relevant* actors to participate in the programme – besides network effects this is also relevant because of current public procurement prohibiting any form of collusion. Consequently, a relatively high degree of accessibility to the programme is required. However, the rehabilitation programme should not be 'plagued' by radically diverging interests and free-riders that hamper self-organisation, and should not contain incomplete and inconsistent immaterial resources. But on the other hand, a critical mass of participants is desired such that there are sufficient immaterial resources that facilitate the programme's operation and lead to network effects. Therefore, it should consider general rules that are able to set access criteria. For instance, actors whom are willing to actively participate in the programme, have the right certification and conform to the protocols and standards determined in the programme process, must be granted access to participate in the programme. With right certification is meant that public and private actors adhere to national codes and specifically private actors need to be registered and licensed companies.

Governance: technical design characteristics and programme policy arrangements

The rehabilitation programme should provide incentives and facilitate cooperation and a collective mission such that collective action problems the sector is currently facing can be overcome. Consequently, a balance between autonomy and collective action needs to be found. Considering autonomy to be related to the amount of strategic resources pooled in the civil engineering sector, public actors should remain in control over their owned assets and so will the technological, human and material resources utilised by service providers. The only resources that are pooled and actively shared within the context of the rehabilitation programme are the immaterial resources – i.e. the codified knowledge that are accessible within the rehabilitation programme's digital platform.

In such a way, a high degree of decentralised coordination is retained, given that: there still remains a competitive element within the rehabilitation assignment of bridges and viaducts, and the offering of rehabilitation projects is not centrally controlled by a higher-order public authority. Albeit, new incentives that focus on quality instead of price stimulate innovation, participation through self-organisation and process standardisation add new dimensions of coordination to the civil engineering sector.

Furthermore, some transition towards a decrease in autonomy can be expected from the position of public actors, where (according to 'de bouwagenda') similar projects are batched regionally across all asset owners within a specific region; given that some strategic resources such as capital and management will need to be pooled for example in the form of a strategic alliance among regionally clustered public actors. This dynamic, however, has little effect on the diffusion- and adoption-processes of immaterial resources which is the current focus of the thesis, besides the fact that it is able to stimulate innovation and knowledge development and sharing (problem solving and learning (Winch et al., 1998)).

Taking the above mentioned into account, the programme arrangements should be based on the sector's polycentric organisational structure and complemented by the digital platform's technical design characteristics. Regarding the latter, the digital platform's technical design is characterised by virtual organisations (Evaristo & Fenema, 1999) that supports the diffusion and adoption processes of immaterial resources across projects and organisational boundaries of actors in accordance with the programme arrangements. These arrangements include the agreements between the participating actors regarding standards (e.g. technical or policy standards), protocols (e.g. rules of engagement), incentives and monitoring. The programme process governance is responsible for establishing policies and monitor their implementation within the rehabilitation programme by the participating actors. Naturally, as the programme lifecycle progresses towards the programme delivery stage, the programme process governance should also incorporate the governance structures that support the programme delivery stage – i.e. sufficiently align the technical design characteristics and programme arrangements. This includes selecting the processes (e.g. procedures) and structures (e.g. modes of organisation) that are able to coordinate and monitor the critical functions.

In the previous design step, the conditions for a programme to be accessible are derived. As a next step, incentives, protocols and standards need to be established such that the participants are interoperable and able to interconnect. Subsequently, public and private actors should be appointed to the appropriate roles within the rehabilitation programme and be granted specific (decision and property) rights accordingly (Ostrom, 2008; Kunneke, 2013; Menard, 2018). Where, the rehabilitation programme delivery needs to be continuously monitored to ensure that all participants are appointed appropriate roles and behave accordingly, and the immaterial resources are accurate and appropriate at any given point time. For instance, by means of network governance where actors monitor each other and correct each other's behaviour through auditing processes and implementing (gradual) sanctions in case of misbehaviour – sanctions need not be monetary and could instead be based on reputation – that subsequently lead to corrective measures (Ostrom, 2008; Kurapati et al., 2012). Given the participatory characteristics of the rehabilitation programme, establishing and monitoring programme arrangements by means of network governance is an appropriate mode of organisation. However, some monitoring activities may require a third-party that embodies a 'light' variant of a Programme Management Office (with 'light' implying democratically appointed in the design process and of supervisory nature); such as granting and monitoring programme access and facilitating conflict resolution mechanisms (V. Ostrom et al., 1961; E. Ostrom, 2008). The underlying principle is that, in hybrid structures interactions among actors are relational instead of transactional and oriented toward long-term collaboration across

project and organisational boundaries (Menard, 2012). Moreover, the 'network' view on governance stimulates the networked characteristics that are desired in the rehabilitation programme where interoperability is ensured through consistent and well organised agreements (Jones et al., 1997; Menard, 2012).

Coordination: operation and participation

The operation of the rehabilitation programme of Dutch bridges and viaducts is fundamentally based on participation and self-organisation among the involved actors. Operation includes all of the activities within the programme's virtual organisation, leveraging digital technologies that ensure that the programme's critical functions are satisfied. Here, one should think of activities surrounding the reciprocal exchange of immaterial resources of specific project processes between similar rehabilitation projects and actors but also upkeeping the integrity of the programme. Shared situational awareness empowers autonomous actors to self-organise and collectively act within the virtual organisation enabling the programme's operation (Kurapati et al., 2012). For example, public actors that are geographically distributed yet share similar assets characteristics and problems should be empowered to exchange contextual information that improves their decision-making capabilities. Likewise, the same principle holds for other forms of self-organisation and collective action among arbitrary actors within the programme; such as sharing immaterial resources across similar rehabilitation projects or enabling decentral control of one another's actions. However, for this to happen, decentral coordination mechanisms are required that enable participation (Brazier, 2011; Priya Datta & Christopher, 2011). This is also in line with the programme's hybrid organisational structure and networked governance that relies on decentralised and autonomous yet networked actors in a polycentric context.

In the rehabilitation assignment of bridges and viaducts, digital technologies facilitate among others collaboration and learning, and the availability and uniformity of immaterial resources (see table 10 for an overview of the identified benefits of digitisation). Such a digital environment is believed to contribute to the asset management maturity of public actors and the productivity of private actors through process innovations and the network effects of interconnected resources (table 10). Here, actors need to be interconnected and interoperable such that they are able to coordinate with one another and exchange information. This implies that their systems abide by the technical standards and are connected to the programme's digital infrastructure such that they are able to participate in the virtual organisation. Or in other words, the self-organisation and collective action among participants coordinated through shared situational awareness – facilitated by interoperable digital systems – and appropriate incentives. For instance: reputation, performance and financial incentives can coordinate behaviour between actors and to a certain extent ensure the programme's integrity (e.g. reputation mechanisms and past performance system in combination with peer reviewing for joint corrective actions). The previously mentioned information is inserted in the template to provide overview (table 23).

Table 23: overview of the design-choices made for the programme delivery stage, summarises information presented in section 5.4.6 (Author's own elaboration)

<table>
<tr><th colspan="3">Overview of design-choices for the programme delivery stage</th></tr>
<tr><th colspan="2">Objectives</th><th>Expectations</th></tr>
<tr><td colspan="2">Collective action
Improve overall rehabilitation project performance and success</td><td>Actors are able to self-organise
Knowledge and innovations are developed, diffused and adopted across rehabilitation projects and actors</td></tr>
<tr><th colspan="3">Critical functions</th></tr>
<tr><td colspan="3">Actors are able to: self-organise the development, diffusion and adoption of innovation and knowledge across rehabilitation projects and organisational boundaries

System control: Interests of actors are aligned and immaterial resources are accurate & appropriate
Capacity management: Sufficient participating actors and resources are available
Interconnection: Actors are networked and resources are linked
Interoperability: Actors are able to communicate, organise and exchange resources on the basis of rules and standards</td></tr>
<tr><th>Technology</th><th>Alignment</th><th>Institutions</th></tr>
<tr><td>Technological architecture
A digital platform facilitating inter-organisational and cross-project processes.</td><td>Access
Open access to all relevant actors whom are willing and eligible to participate.</td><td>General rules
Certification and conformance to programme protocols and standards while taking into account formal laws (e.g. procurement law) and cultural constraints (e.g. autonomy, opportunistic behaviour).</td></tr>
<tr><td>Tech. design characteristics
Virtual organisation that facilitates the diffusion and adoption of immaterial (strategic) resources across project and organisational boundaries.</td><td>Governance
Network governance based on relational contracts and hybrid organisational structure(s): establish policies and monitor their implementation</td><td>Programme arrangements
Tasks of programme management office, degree of autonomy, roles, incentives, protocols, standards and monitoring that enable long-term collaboration and participation</td></tr>
<tr><td>Operation
Exchange of immaterial resources of specific project processes and bridges and viaducts, and ensuring the integrity of the programme.</td><td>Coordination
Reputation, performance and financial incentives, technical standards and digital technologies that facilitate shared situational awareness</td><td>Participation
Self-organisation, collective action and shared situational awareness</td></tr>
</table>

5.4.7 Aligning the rehabilitation programme design with the three-layered architecture

The rehabilitation programme presented in this thesis is a participatory system – more specifically, a system-of networked-systems (Brazier, 2011) – of interconnected autonomous actors that are part of the polycentric civil engineering sector of the Netherlands. Therefore, the three-layered architecture has an important role in the conceptualisation of the programme delivery stage's design.

It serves as a tool to structure and relate the programme's technological and institutional design characteristics with one another. In the social layer the institutional design is most dominant whereas in the communications and technical layers the technological design is more dominant. Based on the information provided in table 23, an integrated representation of the relation between the alignment perspective and the three-layered architecture can be derived which nicely visualises how the different abstraction levels are related to one another and to their respective social, communications and technical layers (figure 16).

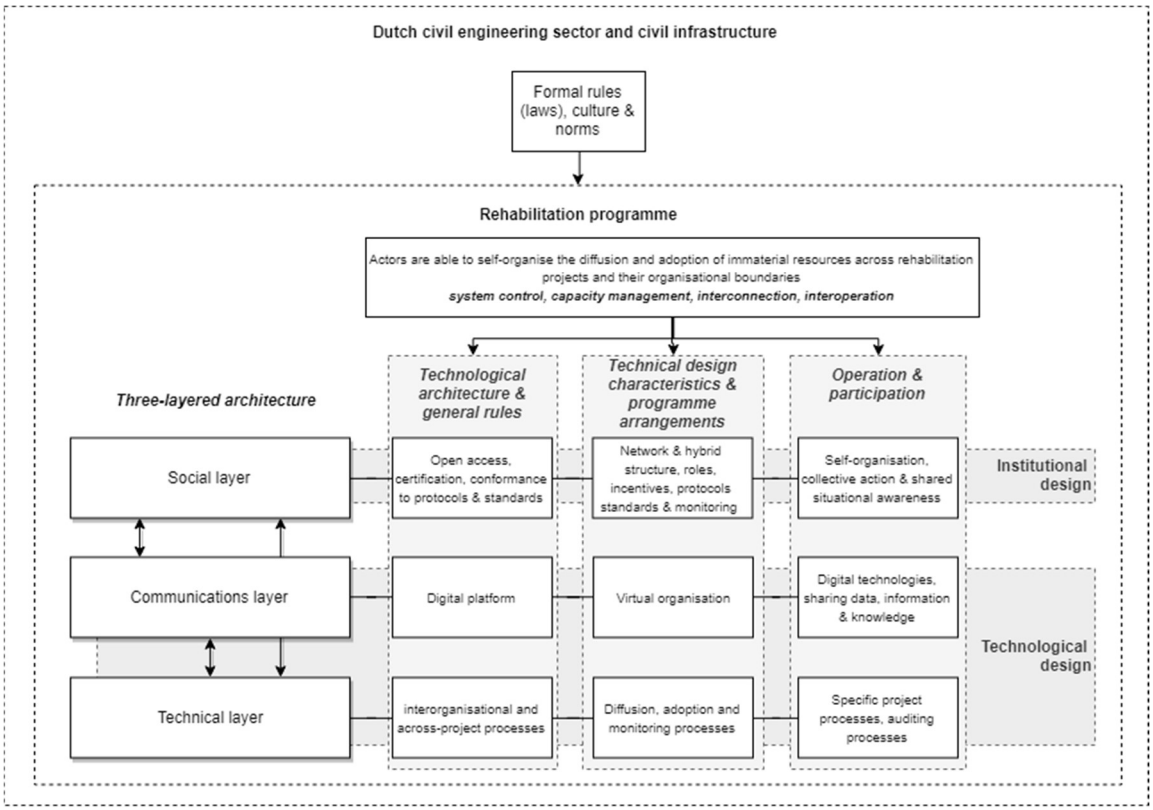

Figure 16: the programme design in relation to the three-layered architecture of participatory systems (Author's own elaboration)

From a different level of resolution, an operational perspective is provided to wherein the rehabilitation programme delivery can be seen as an iterative process of coordinating the adoption and diffusion of innovations and knowledge throughout the execution of the programme portfolio (i.e. all the projects that are associated with the programme and for which synergies can be enabled – such as standardised processes and technical interfaces) according to the programme arrangements (e.g. roles, protocols, standards and incentives) and digital platform's design characteristics (virtual organisations that facilitate (figure 17).

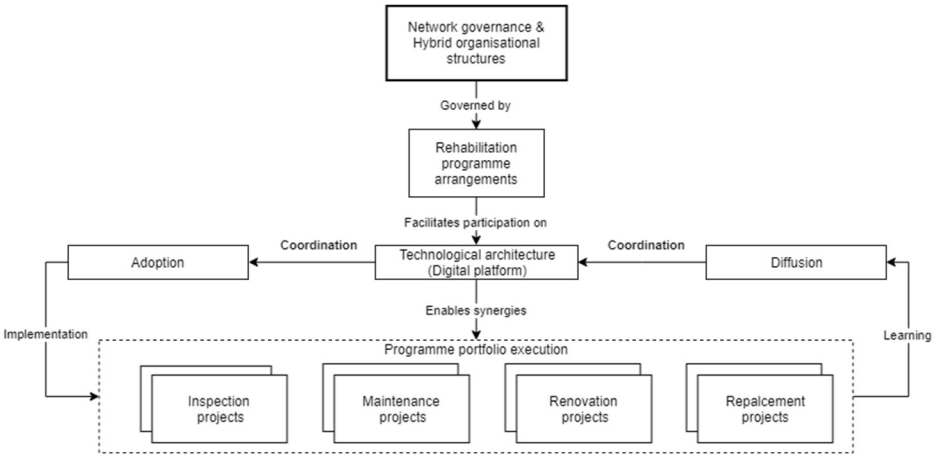

Figure 17: Rehabilitation programme design from an operational perspective (author's own elaboration)

The exact and detailed design characteristics of the digital platform and programme arrangements are not within the scope of this thesis. According to Gall's law introduced in the beginning of this chapter, such a system needs to start as a relatively simple system and evolve into a complex system. Therefore, the detailed design of the rehabilitation programme, can only be developed as a process of actual (real-world) implementation.

5.5 Framework verification

As a final step for the design of the framework, it needs to be verified. Verification implies to ensure that the requirements on which the design is built are satisfied. However, even though the requirements are associated with specific parts in the conceptual framework, they are not tested by means of simulation, experimentation or real-world implementation (Brazier et al., 2018). Therefore, the verification should be seen as an exercise of linking requirements to specific parts of the conceptual framework rather than 'hard-verification'. In table 26 the conceptual framework is mapped onto the requirements.

Table 24: Verification of requirements as an exercise of linking requirements to the conceptual framework

	Verification of requirements	
	Requirement	**Verification**
Functional requirements		
FR 1	Addresses the challenges of the rehabilitation assignment	• Programme allows large number of rehabilitation projects to be coordinated. • Project complexity may dealt with by leveraging digitisation, standardisation, knowledge, innovation and communication. • Complexities associated with decentralised institutional character may be mitigated with hybrid organisational structures that take into account polycentric nature of the sector. • Trust may be improved by means of participation in (design) processes, governance, protocols and incentivisation.

FR 3	Stimulates collective action of public and private actors	Collective action may be stimulated through participation, negotiation processes, self-organisation and shared situational awareness that coordinates activities and aligns interests.
FR 4	Engages the civil engineering sector in participative processes	The conceptual framework is based on participatory systems design and process design is inherently participatory.
FR 5	Maintains autonomy within the polycentric civil engineering sector	The implementation of hybrid organisational structures may facilitate polycentric governance through long term relationships among participating actors.
FR 6	Facilitates cross-project coordination and interorganisational collaboration	The rehabilitation programme's higher-order strategic objective satisfies this requirement. Additionally, programme arrangements such as protocols and technical standards may allow the interoperation and interconnection of projects and actors.
FR 7	Establishes higher-order strategic objectives	The established higher order strategic objective is: the self-organisation of actors around the diffusion and adoption of immaterial resources across projects and organisational boundaries
FR 8	Adapts according to contextual changes	Adaptation is an element facilitated in the superstructure. Furthermore, it is an inherent property of the programme process.

Behavioural requirements

BR 1	More diffusion and adoption of knowledge, innovation and standards than current practice	According to chapter 3, the civil engineering sector rarely diffuses and adopts knowledge and innovation. Implementing digitisation and the programme's design facilitates this.
BR 2	Reduction in cost overruns and time delays of projects more than current practice	The rehabilitation programme aims to improve the sector's productivity through standardisation, innovation, digitisation, knowledge development and to address the increasing complexity of projects by means of coordination and collaboration.
BR 3	Higher-order strategic objectives realise synergies across projects	The higher order strategic objective identified attempts to standardise, innovate and develop knowledge across rehabilitation projects.
BR 4	Shift towards sector-wide and long-term thinking (instead of inter-organisational and short-term)	Hybrid organisational structures and network governance are based on long-term relational contracts.
BR 5	Communication, self-organisation and deliberation among public and private actors	Programme process, design process, operation & participation and programme arrangements may satisfy this requirement.
BR 6	Implement changes in and learn from processes over time	Implementation and learning is part of the framework's superstructure. Furthermore, the development, adoption and diffusion of immaterial resources facilitates learning on the project-level.

BR 7	Make joint corrective actions across public and private actors	Shared situational awareness and digitisation facilitates taking joint corrective measures

Structural requirements

SR 1	Adaptation is interoperable with governance, coordination and processes	Adaptation, governance and coordination are part of the framework's superstructure and linked to one another.
SR 2	Approach can be aligned with existing initiatives	The implementation of the framework builds on 'de bouwagenda', 'marktvisie' and 'DigiDealGO' initiatives. This starts from stage 1 and affects the implementation discourse as a whole.
SR 3	Approach's lifecycle consist of multiple stages	The programme lifecycle consists of identification, design, delivery and closure stages. On top of which a programme process is designed.
SR 4	Organisational structure is compatible with polycentric civil engineering sector	Hybrid organisational structures were chosen such that polycentric governance is facilitated.
SR 5	System is enabled by Information & Communications Technologies	The rehabilitation programme is a participatory system that is by definition enabled by distributed ICT. Coordination in multiple stages (design and delivery) explicitly refer to using ICT. Furthermore, the rehabilitation programme implementation builds on the digitisation movement of DigiDealGO and suggests the use of a digital platform, virtual organisations.
SR 5	System relies on institutions to structure (social) behaviour	In the design process an institutional design is provided. Programme governance and coordination also use institutions such network governance and incentive structures. Furthermore, an organisational structure is also an institutional construct.

Experiential requirements

ER 1	Sense of trust, empowerment and cohesion	Participatory systems are designed for trust and empowerment. Cohesion is facilitated through collective action in which interests are aligned.
ER 2	Interaction is reciprocal and fair	A prerequisite for the programme design are reciprocal interactions: shared situational awareness and adoption and diffusion.
ER 3	Transitions and processes are perceived as reinvigorating for the sector	The implementation of the rehabilitation programme may cause a transition towards sector reform. However, whether this is perceived as reinvigorating cannot be verified even with a 'soft' approach.
ER 4	Sense of autonomy	
ER 5	(Public & private) Actors willingly participate	Actors are autonomous and thus entry to the programme is not based on hierarchical authority but on relationship and willingness.
ER 6	Feeling that public actors take initiative	In round 1 of stage 1, the public actors that were engaged in 'de bouwagenda', together with are proposed to take initiative.

5.5 Chapter summary

In this chapter the conceptual framework of governance and coordination to address the challenges of the rehabilitation is designed according to the identified functional, behavioural, structural and experiential requirements. These requirements are elicited from the practical and theoretical needs, desires and values identified in chapters 3 and 4. The conceptual framework consists of a superstructure that relates the programme's lifecycle stages and their respective coordination elements to the governance, implementation and learning, and adaptation elements; these elements are described in section 5.2. The process design and design process were described in section 5.3. The process design should be seen as an additional layer on top of the programme lifecycle that facilitates the stage activities. The design process is associated with the second stage of the lifecycle and is responsible for the design of the programme delivery stage.

In section 5.4 the first and second programme lifecycle stages of the conceptual framework were implemented in the rehabilitation assignment of Dutch bridges and viaducts. The aim was describe in more detail and context how the conceptual framework works and should be implemented. More specifically, to facilitate collective action and increase the productivity of actors in the rehabilitation assignment. Applying the conceptual framework presented an outline of the programme process design and design process of the rehabilitation programme. The purpose of the programme process design is to increase the willingness of the sector to participate within the rehabilitation programme given that they cannot be forced into it. The first stage and respective rounds (round 1 and 2.1) engage actors to participate in the programme identification and design. Subsequently, the programme design is the second stage and facilitates the design process (round 2.2), the goal of the design process is to conceptualise and implement the programme design while taking into consideration both technological and institutional perspectives of the design. The alignment perspective facilitates the coherency between the technological and institutional designs such that the programme's performance is ensured. This design outlines the governance, coordination and implementation of the programme delivery stage of the framework which is initiated in round 3 of the programme process. The derived rehabilitation programme is oriented around establishing a digital platform where actors are able to self-organise the development and sharing of immaterial resources across project and organisational boundaries such that the sector's productivity can be improved. In short:

- The rehabilitation programme represents a multi-stage approach to develop and operationalise a participatory system-of-networked-systems enabled by ICT embedded in a broader distributed sociotechnical system that is characterised by its polycentric nature.
- The mission of the rehabilitation programme to facilitate collective action and as such increase productivity by means of the self-organised development, diffusion and adoption of knowledge and innovation across projects and actors. This leverages standardised technical and institutional processes.
- The stages are organised as a process wherein through deliberation collective action problems are resolved (i.e. obstacles withholding the sector from coordinated action and establishing collective interests are overcome) and in the design process the delivery stage is designed.
- In the first two stages, governance and coordination is based on engaging in policy network & deliberation activities. Hence, the governance and coordination gradually develops into maturity for which a programmatic approach to the rehabilitation assignment can be delivered.
- As a result, the delivery stage of the rehabilitation programme is governed by means of network governance and hybrid organisational structures to establish and monitor the programme arrangements and digital platform, and coordinated through incentives, technical standards and digital processes.

6. Validation

A networked approach is desired but currently not feasible, a transition and culture change is necessary

This chapter answers the third sub research question: *can this be validated and how?* The goal is to validate whether the conceptual framework of governance and coordination satisfies the identified requirements relevant to address the challenges of the rehabilitation assignment. More specifically, whether the required productivity growth is facilitated by means of collective action in a polycentric system facilitated by institutional reform, digital technologies, standardisation, knowledge sharing and development and innovation. The conceptual framework represents an approach where, within a polycentric system, a network of projects and autonomous actors is established that facilitates collective action - i.e. a networked approach. This *network approach* is associated with programmes since it manages multiple projects to achieve higher-order strategic objectives (such as collective action) and is thus the approach is referred to as a rehabilitation programme in the previous chapters.

In accordance with the method, validation is done by means of semi-structured interviews with experts and thematic analysis (Braun & Clarke, 2006). Before a semi-structured interview was conducted, a short presentation was given that provided the (to be interviewed) expert with the context of this research. The framework presented in this thesis was validate, meaning that the actual conceptual framework and its implementation was abstracted, resulting in a comparative validation between three (recognisable) approaches each having a different effect on the governance and coordination of the rehabilitation assignment.

Criteria such as *standardisation*, *digitisation*, *innovation*, *knowledge development and sharing, resilience* (adaptability and awareness to contextual changes) and *proactivity* (participation and reciprocity) contribute to the sector's productivity. On the other hand, the assignment can be tackled on the basis of either a *project, portfolio* or *network approach*. Furthermore, depending on the chosen approach, each criterium has a different effect on the productivity of the sector. In Appendix B the interview process, the code book, thematic map and direct analysis are covered in detail. In short the questions in the interviews addressed:

- Whether the criteria are meaningful, which are important and if any are missing;
- Whether the three approaches are representative and if there are any other approaches;
- Whether the respective effects of a specific approach on the criteria are correct;
- And finally, which of the presented approaches is most feasible and why.

The direct answers to the questions provided a validation of the approach presented in this thesis, but it also sparked a deeper conversation around the context of this research and the broader civil engineering sector. The latter qualitative data was used for further interpretative thematic analysis. In the remainder of this chapter the results of the interviews are presented as follows: first, the conclusions drawn from the direct answers to questions are provided (the extensive analysis is found in appendix D6), and second, a thematic analysis of the qualitative (interview) data is presented. This complements the first

step by providing a more in-depth and interpretative perspective to the expert's perceptions with respect to the rehabilitation assignment.

6.1 Direct responses: opportunities and barriers towards a networked approach

In the developed conceptual framework of governance and coordination presented in this thesis, criteria were identified that influence the productivity growth. The framework's design takes into account both the barriers hampering collective action (e.g. short-term competition) and opportunities to increase productivity (e.g. such as digitisation).

6.1.1 Criteria related to the sector's productivity growth

In the interviews, a selection of criteria were presented that contribute to productivity growth. These were all perceived as meaningful. Nevertheless, experts explicated the need for both the important opportunities (such as innovation, digitisation, knowledge sharing and development, standardisation and collaboration) and barriers (such as rules and regulation and individual interests driven by competition) that withhold the sector's collective productivity.

Moreover, it appears that innovation, albeit overall perceived to be the most important criterium, is a stained term that encapsulates multiple concepts including technological innovation, process innovations, institutional innovation and cultural innovation. Thus, when referring to innovation, it becomes important to indicate in what context innovation is used. Additionally, the interrelatedness of the criteria was touched upon multiple times. For example, two experts mentioned the ageing and shrinking workforce as a pressing issue (barrier) for the sector; automation is an important innovation for mitigating this issue. However, automation and industrialisation were indicated to be products of digitisation and standardisation. Therefore, strategies that leverage this interrelatedness are expected to be more effective in realising the productivity growth. Such strategies are likewise considered to be part of the designed conceptual framework. For example, in the conceptual framework, distributed ICT leverage standardised interfaces for interoperability.

Surprisingly, the criteria of resilience and proactivity did not receive as much attention. However, one could argue that proactivity and collaboration are closely related and have similar effects across the different approaches – with this in mind, a proactive (and thus also collaborative) sector does indeed seem to be important in the face of the rehabilitation assignment. In the conceptual framework participation, deliberation, reciprocity and collective action are important drivers for collaboration. Furthermore, resilience seems to be primarily associated with the flexibility of humans and organisations in the sector to identify and successfully react to new opportunities and challenges while operating within the current institutional infrastructure. Although this criterium is meaningful and is indicated to be necessary by means of a clear and contemporary example – the PFAS crisis – this is currently not to the case. The conceptual framework is designed for adaptability to changing contexts over time.

6.1.2 A balancing act between three approaches

In continuation of the interview, the topic shifted to the different approaches with which the rehabilitation assignment can be tackled. Three approaches were presented, namely a project, portfolio and network approach each with different characteristics. According to the experts the approaches seem to be a correct conceptualisations of the different approaches with which the rehabilitation assignment can be tackled and are thus considered to be representative. More specifically, the project approach was unanimously associated with the current approach and all were familiar with some form of what the experts associated with the portfolio approach. Mostly in the form of a long-term contract between a

public and private actor spanning multiple engineering structures and were said to facilitate more innovation than the project approach. On the other hand, the network approach, with the exception of the rehabilitation assignment of the municipality of Amsterdam, has not been introduced in the civil engineering sector. Nevertheless, as was indicated, the approaches are related and can be seen as evolutions of one another. Implying that the portfolio approach is an evolution of the project approach, and the network approach is perceived to be an evolution of the portfolio approach – making these approaches combinable with one another.

The effect that the criteria have on the sector's productivity is dependent on the selected approach and dictates in what way they should be managed. Each approach is a different embodiment of how the sector can be governed and coordinated to realise the sector's productivity growth as a whole. For example, portfolios lead to a lot of innovation, more so than projects, this is due to the certainty and repetition making it more attractive to invest in innovations; but if these innovations are diffused in a network and causing new innovations they may lead to more progression. Nevertheless, diffusion requires interconnectedness through standardised technical and institutional interfaces.

At the resolution of the conceptual framework presented in this thesis, namely that of organisations and projects, the identified effects of the criteria were validated by most of the experts across all approaches. However, a more nuanced image of the approaches is achieved if the barriers are included – that is, the effect of contemporary individual interests, competition and culture within the sector on the feasibility of the approaches. Additionally, some experts mentioned that standardisation incorporates top-down and bottom-up processes in all of the approach due to the need for consensus and authority (enforcement) by dominant actors within the sector – the leading authority for standardisation (codes) in the Netherlands is the NEN whereas public actors (asset owners) implement the codes in their processes. Within the conceptual framework, in the delivery stage, a hybrid organisational structure may facilitate third-party coordination such as the NEN to 'enforce' standards under the condition that this is agreed upon by the participating actors.

6.1.3 Current feasibility versus desired transitions

Including additional criteria gives us a more nuanced image, where it becomes apparent that the project approach is currently the most feasible. This is mainly because of the existing barriers: the way the sector is currently organised and existing individual interests (project-centric organisation and short-term competition respectively), the in-place yet out-dated institutions (rules and regulations), but most important of all, the sector's culture (culture). Next in line with regards to feasibility is the portfolio approach, given its direct similarity with the project approach and familiarity within the sector. Albeit, experts state that even portfolio approach is difficult to fully implement and its contribution to lower barriers such as culture and individual interests is debatable.

Furthermore, all experts expressed a desire for a transition towards a networked approach. It has even been expressed to be the sector's *only* remedy for alleviating the challenges of the rehabilitation assignment. However, for the same reasons to the portfolio approach, it is currently not feasible – especially since it is less familiar and requires systemic changes to be implemented across the sector. Therefore, in order to get there some in-between variant seems to be necessary. Or in other words, a stepwise process within which the necessary changes to the sector can be realised. As aforementioned, the approaches are combinable, hence, the portfolio approach can function as an the in-between step and then to continue by constructing an overarching network that connects portfolios and projects. In such a way, the network approach becomes a combination of the previous approaches thus maintaining characteristics of portfolios and projects.

The conceptual framework builds on top of the existing project oriented and polycentric organisation of the sector and initiates the process of developing a network – supported by a technological and institutional – that spans multiple projects and organisations facilitating collective action. Thus, it acknowledges the current infeasibility of a network approach (due to existing collective action problems) and the need for a gradual transition (the multi-stage approach to 'network' delivery).

6.2 Thematic analysis: a necessary impetus away from project-centrism and towards a networked approach

In the previous section, the desire for a networked approach is expressed and is considered as the only viable option for addressing the challenges of the rehabilitation assignment. However, experts mentioned that, due to the existing barriers the project approach is most feasible and even the implementation of portfolios is at times difficult. The key challenge identified is resolving the collective action problems such that a transition towards a networked approach can be realised. This transition needs to be gradual, overseeable and leverage existing initiatives (such as 'de Bouwagenda') that is able to exploit the interconnectedness of the presented approaches. The intention of the conceptual framework presented in this thesis (chapter 5) is to provide the tools and rationale that can govern and coordinate such transition.

6.2.1 Theme identification

A thematic analysis of the conducted interviews attempts to construct a more nuanced image to the overall validation. The identified codes and themes are presented and described in Appendix B4. These themes are related to the main research question: *"can governance and coordination be designed to address the challenges of the rehabilitation assignment?"*. Four key themes were identified, namely:

- Organisational changes within the sector;
- Firm grip of project-centrism;
- Cultural paradigm-shift;
- Transition path towards a networked approach.

In short, dealing with the rehabilitation assignment requires organisational change. However, the current approach is dysfunctional and withholds those changes from occurring. Therefore, a cultural paradigm shift is needed, one that is able to facilitate a system disruption. Yet, in order to do so, a transition is necessary for the gradual implementation of networked approach.

The following subsection introduces the four themes and explicate how they are interrelated, the last subsection relates the themes back to the conceptual framework described in chapter 5.

6.2.2 Thematic analysis description

Organisational changes within the sector

For the challenges in the rehabilitation assignment to be addressed effectively, organisational changes are needed within the sector. The experts expressed the need for institutional renewal. More specifically, institutional renewal that leads to new incentives, new business models, and better rules and regulation wherein the roles between public and private actors are redefined. For example, table 12 presented in chapter 4 describes such measures. Therefore by means of reorganising the sector a more collaborative sector is expected to emerge, that is able to facilitate more innovation, standardisation, digitisation, and knowledge development and sharing. This is also the ambition of the civil engineering sector with

regards to the rehabilitation assignment (chapter 4). As a consequence of these measures, practices are reformed, which are suitable for the implementation of the desired networked approach.

However, there still are many barriers that have yet to be overcome. Particularly with regards to rules & regulation and culture that are embedded within the civil engineering sector. The main cause for the existence of these barriers was attributed to the in-place project-centric organisation of the sector.

Firm grip of project-centrism

Individual interests and short-term competitive strategies are caused by the current project approach. Additionally, obstacles in the rules & regulations decelerate innovation, digitisation and knowledge development and sharing – this is also supported by table 11 presented in chapter 4. Hence, the project approach has been expressed to be dysfunctional and unable realise the rehabilitation assignment. Nevertheless, the sector appears to be stuck in the current status quo, since there are many perceived uncertainties and difficulties towards new approaches; especially the networked approach. Therefore, the aforementioned barriers negatively impact the sector's readiness to adopt new approaches.

> *"However, in order for that to happen certain barriers must be overcome since we have to start organising ourselves differently, we have to adapt the rules and regulations etc. If you look at the public procurement law, it is oriented around the fairness of competition among market parties to earn projects." – van der Vaart*

There is a clear contradiction is observed. On one hand, the sector has a strong desire for a network-like approach to be implemented. Yet, on the other hand, the sector is said to be "not ready yet" and any transition is firmly resisted by what appears to be perceived uncertainties and difficulties towards adopting new approaches. Therefore, a cultural paradigm shift is needed such that the project-centric view to the organisation of the sector can be replaced.

Cultural paradigm shirt

In order for the sector to break free from project-centrism, a system disruption is necessary that is able to overcome the aforementioned barriers and facilitate collective action. This implies that collective interests should prevail over individual interests. Additionally, increased sense of urgency and social responsibility are needed and are expected to contribute to the transition towards the adoption of a new approach and the acceleration thereof. Furthermore, becoming more transparent and open to new entrants within the sector are believed to improve the productivity and innovativeness of the sector. However, the contemporary culture of the civil engineering sector is incompatible with such new approaches. Therefore, a cultural paradigm shift needed. The desire expressed by the experts is, for such a paradigm shift, to put the emphasis on increasing the sense community (cohesiveness) and improve collaboration such that long-term thinking and collective interests may gain a foothold in a market otherwise dominated by short-term competition and thus conflicting individual interests. For example, obtaining exclusivity rights for important innovations do not improve the sector's productivity nor does the retention of knowledge.

> *"If you maintain this view as the dominant view, then a network approach will not be able to fully flourish. Stepping away from this paradigm is a requirement for a network's success. So this requires a practical way to stimulate a network approach. For instance a way where it becomes profitable to share knowledge with one another. Together we know more, adopting this perspective causes a positive feedback loop and reward mechanism to share knowledge […] For the network approach however, the right boundary conditions need to be facilitated such that it becomes easier to share knowledge. We can see the initiative of de Bouwcampus taking*

shape but the way that it is currently organised is not sustainable and I do not expect this to change within the forthcoming 5 years." - Mak

A paradigm shift is a slow process, as fundamental cultural change that is able to implement a networked approach may take years to realise. The appropriate climate for adopting 'new ways of thinking' needs to be facilitated and carefully nurtured. More specifically, such a climate should embody a transition path wherein the organisational and cultural transition becomes gradual and overseeable.

Transition path towards a network approach

In this transition path, experts expressed the need for public actors to take initiative in the rehabilitation assignment, provide the appropriate incentives for private actors to change and to leverage the combinability of the approaches. In such a way, although a network approach is desired, its gradual implementation is facilitated for which portfolios seems to be a logical stepping stone. Moreover, since collective action is needed in this transition, large initiatives with many initial participants were said to be ineffective due to the fact that there are many diverging individual interests that result in impasses. Instead, a 'think big act small' mentality is believed to be more effective as collective action is more easily facilitated in smaller groups and momentum is maintained. As an extension of the 'think big act small' mentality, pilot projects are effective in mechanisms in the transition for which regional and local public actors are key facilitators due to their flexibility. Finally, leveraging the effective strategies that harness the interrelatedness of the identified criteria for productivity growth can contribute to the overall transition and foremost in the pilot projects resulting in more innovation and knowledge development – for example open innovation that leads to both innovation and interorganisational alignment and standardisation.

6.3 Chapter summary

In this chapter the conceptual framework proposed in this thesis is validated by analysing expert interviews. The deductive analysis validated the identified criteria and barriers of productivity growth in the sector. Furthermore, it suggests that a network approach is desired; however, a stepping stone such as a portfolio approach is necessary to move from the current project approach to the network approach. In the previous subsection a narrative was presented on the basis of thematic analysis of the expert interviews. This inductive analysis complements the deductive analysis in the former section on the basis of the interview questions.

The narrative indicated the need for a transition path towards a networked approach such that the necessary organisational and cultural changes are realised to break free from the current project-centric organisation of the sector that presents difficulties and uncertainties hampering the sector's readiness. This transition path and similarly the organisational and cultural changes need to be appropriately governed and coordinated. First and foremost to establish collective action among the autonomous yet interdependent public and private actors that make up the polycentric civil engineering sector. Second, facilitating appropriate cross-project coordination and interorganisational collaboration depending on the approach that is implemented to ensure productivity growth. For example, coordinating the implementation and scaleup of pilot- projects and portfolios across the civil engineering sector.

More specifically, the conceptual framework proposes a way to facilitate both the transition by means of a stepwise and thus multi-stage process and the design and implementation of a networked approach. It has as starting point the current situation and suggests to leverage existing initiatives to establish a participatory programme enabled by ICT, in which hybrid organisational structures are established, that

take into account the polycentric nature of the civil engineering sector, and through which the challenges of the rehabilitation assignment can be addressed.

7. Discussion

A discussion on the implications of the results and reflection on the research

This thesis set out to gain an in-depth understanding of the civil engineering sector in the Netherlands, the rehabilitation assignment of civil engineering structures and the observed challenges from a sociotechnical perspective. Furthermore, to acquire and synthesise relevant theoretical concepts related to governance and coordination that are able to address the observed challenges. And subsequently to design a conceptual framework of governance and coordination for the civil engineering sector (sociotechnical system) or parts thereof and finally to assess the validity of the designed framework. This chapter of this thesis serves as a platform for additional comments and critique on the results and the research itself. More specifically, the designed conceptual framework and its implications, its contribution to academia and added value for the professional audience of the sector, the inconclusive results and the limitations of this research.

7.1 Conceptualising the framework

The case study uses action research as a method of knowledge acquisition, that facilitated the engagement with numerous prominent figures within the sector at multiple occasions – some of them were interviewed. Based on the perceptions and knowledge obtained in this process, multiple sources were consulted that supplemented information with which the case study was constructed (in the constructivist sense). Furthermore, the action research in the case study is exploratory in nature and served to identify the obstacles, trends and developments within the Dutch civil engineering sector and the rehabilitation assignment of civil engineering structures. In combination with academic research, this resulted in needs, desires, values and requirements that shaped the design of a conceptual framework of governance and coordination.

The conceptual framework presented in this thesis captures the development and implementation of a participatory programmatic approach throughout its lifecycle. Hence, it is modelled as a process that continuously adapts according to programme implementation and learning. The programme's lifecycle consists of four subsequent stages of which their activities are subjected to coordination. In turn, the programme's lifecycle is coordinated by programme & process governance. The synthesis of those concepts – i.e. the governance, stages and their coordination, implementation and learning, and adaptation – constitutes the framework's superstructure with the programme's lifecycle at its core. The term programme refers to the establishment of higher-order strategic objectives by managing multiple rehabilitation projects. However, the conceptual framework itself encompasses a network approach that facilitates collective action in a project-based polycentric system.

Furthermore, the designed conceptual framework is implemented onto the case study by using the knowledge obtained from action research and desk research. There is a good fit with the already existing initiatives such as 'de Bouwagenda', 'DigiDealGO' and 'de Marktvisie'. Therefore, the rehabilitation programme, as presented in chapter 5, can be considered as an extension and facilitator of the ideas and measures presented by those initiatives. Standardisation, digitisation, innovation, knowledge

development and sharing, and collaboration underline the current impetus within the civil engineering sector. However, this is constrained by cultural and organisational barriers. This was further validated by the interviewed experts, whom indicated that a stepwise transition is necessary that is facilitated by portfolios, pilot projects and public actors that take initiative. In the delivery stage, assuming that sufficient momentum has been accumulated through participation, actors engage in long-term collaboration and interoperate on the basis of agreed upon technical standards. As a consequence, a system of networked systems can be established wherein an increase in productivity and grip on the problem is realised; this system is represented by the delivery stage's design.

Therefore, and in line with the autonomy of each actor that participates in the rehabilitation assignment, governance and coordination cannot be conceptualised as hierarchical and centralised. Concluding that a different approach is necessary that deviates from the traditional paradigm of hierarchical thinking that currently dominates the programmes literature. But, how can programmes be facilitated without dominant hierarchical organisational structure? There is thus far no readily available answer for this question in the theory, so the orientation of the framework's implementation started to lean toward facilitating the development of such an approach. This resulted in the development of a conceptual framework of governance and coordination based on participation, processes and foremost collective action.

Consequently, if actors are able to collectively shape the programme's objectives and structure, the willingness to participate among autonomous actors in the programme and the willingness to invest resources (such as time and money) is increased. More specifically, due to the fact that the individual and collective interests of the participating actors converge. Thus, implying that collective action can be facilitated due to a perceived benefit of collaborating within such an organisational structure. In support of this train of thought, a process design and design process was included in the lower levels of the conceptual framework's superstructure. The process design aims to stimulate the participation of the actors throughout the programme process whereas the design process, which is part of the process design, aims to stimulate the programme's design in the programme delivery stage consists of technological and institutional designs that need to be coherent with one another such that it is able to facilitate the new perceptions on programme governance and coordination in the delivery stage without a dominant central and hierarchical programme organisation. The design process draws inspiration from the alignment perspective, a framework that aims to coordinate the technological and institutional design of critical infrastructure operation (such as the energy infrastructure) such that their critical technical functions can be maintained and the performance of such systems can be ensured.

7.2 Contribution to existing academic literature and to the civil engineering sector

This thesis suggests that central control is not effective due to the polycentric nature of the Dutch civil engineering sector that is subjected to polycentric governance – this is supported by Elinor Ostrom's research which indicates that the fitting of institutions to specific settings is crucial for the performance of such systems. Therefore, this research contributes to the existing literature of programme management, polycentric systems and governance, and collective action. Additionally, it adds to the literature on participatory systems as this research brings together multiple fields wherein participatory systems thinking has yet to be applied.

With regards to decision-makers in the civil engineering to address the challenges of the rehabilitation assignment. Given that the rehabilitation assignment is still an ongoing issue with no clear solution, the conceptual framework provides an approach with which the current initiatives in the sector are synthesised and collective action is facilitated among diverse public and private actors with diverging interests. The presented conceptual framework supplements the indicated need for a transition towards

a networked approach as indicated by the interviewed experts. More specifically, in accordance with the principle of *'think big, act small'* and through guiding the sector in overcoming perceived obstacles in a stepwise and participative process.

7.3 Inconclusive results

Due to the abstract character of the framework presented in this thesis, the approach can be implementable across a diverse range of issues within the Dutch civil engineering sector. For example, other rehabilitation assignments regarding other civil engineering structures, but also more generally to facilitate long-term collaboration between multiple actors. This claim cannot be validated, however, it could serve as a method for stimulating collective action. The work on process management has already showcased the potential of negotiation in complex policy issues, so the assertion that the programme process presented in this thesis leads to collective action is justifiable.

On the other hand, the design and delivery of the programme requires to be further developed and tested before some claim can be made. Additionally, in its most general form, the framework could be implementable in other domains as well. Any system that is characterised by polycentricity and in which collective action is required could benefit from a programmatic approach that has no hierarchical organisational structure. Take for example, other construction related projects that span multiple governments such as the Dutch energy transition. The energy transition is even more complex compared to the rehabilitation assignment of bridges and viaducts the involvement of prosumers at the household levels. Furthermore, other countries are faced with similar rehabilitation assignments for which this approach can provide the key to collective action.

7.4 Limitations of this research

When starting with the thesis the subject was new and exposed the research to many possible directions. Consequently, a lot of time was spent exploring the topic, going to work conferences, talking to prominent actors, attending symposia and participating in think sessions and design teams. This resulted in a large initial scope that made it hard to focus on a specific problem due to the wicked nature of the rehabilitation assignment. Although the current conceptual framework presents an elaborate approach on establishing governance and coordination by means of programmes in polycentric systems, the scope creep is still noticeable. As a consequence, the research has a theoretical and abstract character; hence, some concepts might come across as ambiguous and would need further elaboration. The state-of-the-art of the framework, presents an outline of the elements it consists of and should be further refined with more detail.

Therefore, the main limitation of this research is the degree to which the conceptual framework can be implemented. The rehabilitation assignment is still an ongoing issue with no clear solution, therefore, the implementation could only reach as far as the second stage of the programme lifecycle where the third stage was designed. Additionally, the implementation and design of the third stage is done by the researcher and could have been facilitated in interactive design workshops. However, due to the iterative nature of this research this idea was not put into action. Furthermore, due to the scope of this research the depth with which concepts associated with the conceptual framework are described is limited.

Finally, some final thoughts with regards to the programme implementation and learning, and adaptation. These concepts should be considered to be of 'utmost importance' when engaging in a programme during its lifecycle. Since programmes last for long time periods and are subject to changing contexts and perceptions. However, besides their description and relation to the framework, it did not get much attention in the framework's implementation. One of the main reasons for this is the static nature of the framework's implementation. If for example the framework would have gone through an

elaborate reviewing process or experiment, implementation and learning, and adaptation could have been facilitated. The elements of adaptation addressed in chapter 5 section 5.4 are the programme process governance which adapts according to changing contexts as the programme evolves and progresses throughout the first two stages of the lifecycle. Similarly, some element of implementation and learning can be observed in rounds 1, 2.1 and 2.2 of the programme process since sub-decisions may be parked and resolved at a later point in time when the programme process has reached a more mature stage and the decision can be made.

8. Conclusion

Governance and coordination can be designed to address the challenges of the rehabilitation assignment

Answering the main research question

This research set out to investigate how the challenges of the rehabilitation assignment of civil engineering structures and in particular bridges and viaducts can be addressed by means of governance and coordination. The main challenges identified are: the large number of rehabilitation projects due to changing functional and structural requirements and deferred maintenance; the increasing project complexity; the increased social and institutional complexity due to short time horizon and decentralised institutional character; and the lack of trust and high degree of competition in the civil engineering sector. Consequently, the following research question was formulated:

Can governance and coordination be designed to address the challenges of the rehabilitation assignment and how?

As the abovementioned question suggests, this research includes a design component. More specifically, the design of a conceptual framework of governance and coordination. The answer to this question, it is broken down into three sub research questions, their key findings are presented in the forthcoming sections.

Which needs, desires, values and requirements for governance and coordination are relevant to the rehabilitation assignment?

From theory, the civil engineering sector is defined as a polycentric system consisting of autonomous yet interdependent public and private actors with diverging interests that in the absence of formally hierarchical relationships are subjected to polycentric governance. Furthermore, the civil engineering sector is characterised as a project-based industry and confronted with inefficient cross-project coordination and interorganisational collaboration that hampers productivity and innovation.

A programme approach, that manages multiple projects in order to achieve higher-order strategic objectives, is an enabler of innovation and standardisation across projects. However, a programme is traditionally governed hierarchically and coordinated centrally through a Programme Management Office. Therefore, for a programme approach to be used in the face of the rehabilitation assignment, collective action is needed and thus different ways of orchestrating governance and coordination are needed to avoid and resolve collective action problems. Network governance, hybrid organisational structures and participatory systems thinking are ways to construct a programme in a polycentric project-based system enabled by ICT. According to the identified theoretical needs, desires and values.

In practice, for the civil engineering sector to be able to tackle the rehabilitation assignment, a firmer grip on the problem and productivity growth is needed to lessen and spread the workload and costs over time. Collaboration, (process) innovation, standardisation, digitisation and knowledge development and sharing are desired by the sector to satisfy both of the aforementioned needs. However, obstacles related

to the actor-behaviour, the market structure, the dominant project-focus, rules & regulations and the lacking sense of urgency withhold the sector from realising the necessary productivity growth, As a consequence thereof, different initiatives such as 'de bouwagenda', 'DigiDealGO' and the 'Marktvisie' express the desire for such a sectoral and cultural reform. For which practical needs, desires and values are identified. The requirements of the conceptual are elicited by matching and integrating the theoretical and practical needs, desires and values.

Can a conceptual framework of governance and coordination be designed to satisfy the identified requirements? And how?

This thesis proposes a conceptual framework of governance and coordination that consists of a superstructure with which a self-organising programme can be orchestrated in a project-based polycentric system to address the challenges of the rehabilitation assignment. The design leverages process, institutional and technological dimensions with a particular focus on the process and institutional dimensions to facilitate collective action through participation. The process design consists of four consecutive stages that represent the programme's lifecycle. Each stage is an aggregate of the previous stages. The purpose of the first two stages is to initiate the negotiation process and design process respectively. This facilitates the transition towards an operational programme where the design-choices, with regards to the accessibility, governance and coordination, determine how the institutional and technological designs are aligned. Furthermore, the conceptual framework was implemented onto the rehabilitation assignment's case information. The resulting implemented design suggests that governance and coordination can be designed to facilitate the development, diffusion and adoption of knowledge and innovation across projects and organisational boundaries enabled by ICT.

Can this be validated and how?

The conceptual framework is validated through the deductive and inductive analysis of semi-structured expert interviews. The experts indicated that although a networked approach is desired and considered to be the only viable approach to the rehabilitation assignment, there are still barriers – such as rules & regulations, individual interests and competition – that withhold the sector from its implementation. Hence, breaking free from the current and dysfunctional project approach, requires cultural and organisational changes that can facilitate collective action and combined strategies that exploit the interrelatedness of the proposed criteria for productivity growth. Therefore, a gradual transition, based on the principle 'think big, act small', is suggested that utilises the portfolio approach as a steppingstone to the network approach. Within this transition, experts proposed that regional and local public actors need to take initiative and utilise pilot projects as a medium for change. This provides substantial evidence, by means of expert validation, that the designed conceptual framework of governance and coordination is indeed able to address the challenges of the rehabilitation assignment. Thereby answering the main research question.

Directions for future research

For directions for future research the following research trajectories can be stipulated: first, an interesting continuation of this research would be to implement the conceptual framework in the real-world rehabilitation assignment of civil engineering structures. More specifically, to implement each step and document progression and important observations that serve as an additional validation or lead to the revision of the framework's design. Furthermore, it would be interesting to add more detail to the framework, more specifically with regards to the institutional and technological design-choices for the programme delivery stage. For example, a higher fidelity and perhaps operational hybrid organisational structure, programme arrangements and digital platform to identify important elements with respect to

micro-institutions and technical design. Ostrom's IAD framework can be of particular use there. Third, it would be interesting to research how different (institutional and technological) design choices impact the development, diffusion and adoption of knowledge and innovations under varying initial conditions. With modelling and simulation the dynamic behaviour of the conceptual framework in the delivery stage can be analysed in a virtual experimental setting. This allows for the testing of many different design combinations under uncertainty. Finally, due to the abstract and generalisable character, the conceptual framework may be implementable onto different cases that involve collective action in project-based polycentric systems. For example, the emergence of decentralised energy communities such as smart-grids or other rehabilitation assignments in the construction industry. The goal in such a research would be to identify useful ways of establishing governance and coordination to facilitate collective action, and to strengthen the validity of the conceptual framework.

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Appendix A: Detailed Methods

In this section the specific research methods and sub research questions are formulated that support the defined methodology and goals. Subsequently, the methods and sub questions are mapped in a flow diagram.

2.2.1 Inquiry of theoretical concepts: literature review

The inquiry and synthesis of theoretical concepts was done by reviewing academic literature collected from the academic repositories Scopus and Google Scholar. Other sources of literature were found through forward and backward reference tracking (otherwise known as 'snowballing'). The following methods were identified

2.2.3 Inquiry of current practices: desk research and action research

Gaining an in-depth understanding of the rehabilitation assignment and the civil engineering sector was done in two ways. First, by conducting desk research that involved internet inquiries policy documents, presentations, articles in professional magazines and news articles. Second, by attending formal and informal meetings such as symposia, work conferences, work-groups and exhibitions associated with the rehabilitation assignment and the civil engineering sector. Table 25 provides a full list of attended formal meetings. Informal meetings with experts were not well documented and thus served as exploratory compass. Each meeting contributed to constructing a thorough understanding of the rehabilitation assignment and the civil engineering sector (goal 1).

Table 25: Overview of attended formal meetings during the period 2018-2019 where information was gathered.

Overview of attended formal meetings during period 2018-2019

Date & location	Event name	Description
23-11-2018, Delft	Dwarskrachten 1	Work conference organised as a part of 'de bouwagenda roadmap 1'. The conference included presentations and workshops related themed around the rehabilitation assignment.
14-1-2019, Kampen	Start open leeromgeving circulaire viaduct	This work conference kicked off of the open learning environment for the circular viaduct at the prototype circular viaduct in kampen. It included presentations and interactive pitches about the circular economy and the rehabilitation assignment.
15&16-1-2019, Rotterdam	InfraTech 2019	InfraTech is a large infrastructure exhibition in the Netherlands for the construction industry. Besides the many participating actors, there were presentations from Rijkswaterstaat related to the challenges of sustainability and infrastructure rehabilitation.
12-3-2019, Delft	Dwarskrachten 2	This work conference was a follow-up of dwarskrachten 1, it included presentations and a plenary session on the use of monitoring and data in inspection projects.
14-3-2019, Utrecht	Bruggendag 2019	Bruggendag is the annual conference organised by the bruggenstichting (bridge association), it included

		presentations on the application of high-tech in bridges, sustainability and the rehabilitation assignment.
28-03-2019, Zwolle	Vervangingsopgave kunstwerken: hoe voorkom je Genoa?	This symposium was organised by (knowledge) Platform WOW to inform on the upcoming rehabilitation assignment and the efforts of different public actors to prevent catastrophic failure.
10-4-2019, Delft	Bijeenkomst leeromgeving circulaire viaduct	This conference included presentations and workshops. It served as the second open learning environment session of the circular viaduct including organisational and cultural aspects of the civil engineering sector.
17-4-2019, Delft	Kickoff 2e versie NTA IFD-bouw beweegbare bruggen	This workshop revolved around further developing the standard for Industrial, Flexible and Deconstructable building blocks in movable bridges in the Netherlands.
26-06-2019, Utrecht	Brug tussen data en toepassing	TNO is a Dutch knowledge institute that in collaboration with Rijkswaterstaat is developing monitoring techniques that deploy novel sensor technology. This symposium included presentations of pilot projects and a panel discussion.
2-10-2019, Utrecht	Rijkswaterstaat marktdag 2019	The annual market day of Rijkswaterstaat is an event for Rijkswaterstaat's partners. In 2019, it revolved around the rehabilitation assignment, innovation, sustainability and collaboration. There were multiple panel sessions, workshops and presentations.

Action research

As a part of the soft systems thinking practice, action research is a way to engage with the research process depicted in figure 5 in the previous section (Checkland & Holwell, 1998). Using action research, through participation and interaction with the problem situation, research themes can be investigated in relation to the real-world problem situation according to the framework of ideas. The process of action research, in turn, informs the framework of ideas in an iterative manner (figure 5).

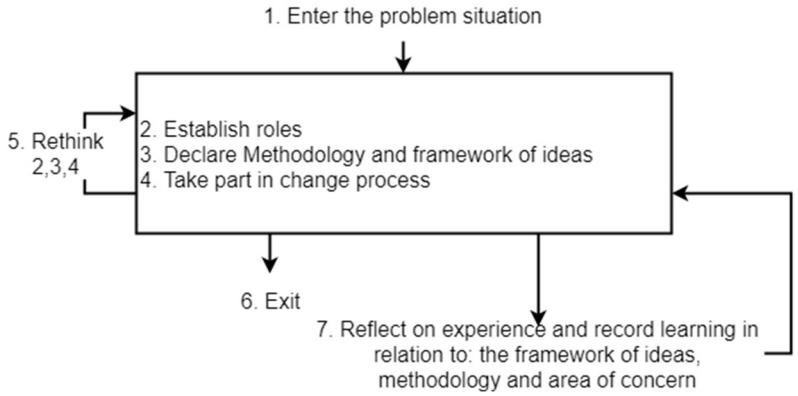


Figure 18: action research process compatible with the standard research process depicted in figure 4. adopted from Checkland & Holwell (1998).

The steps in figure 18 can be further explicated in relation to the research subject:

1. Enter the civil engineering sector and rehabilitation assignment of civil engineering structures;
2. Establish the various roles of public and private actors;
3. Define and develop methodology and framework of ideas (based on beliefs, past experience & theories);
4. Actively participate in debate and interact with experts and stakeholders;
5. Refine and do-over by participating in different work-conferences, work-groups and symposia;
6. Exit 'the system' by withdrawing for participating in events – i.e. stop actively collecting data;
7. Develop definite framework given the learning outcomes obtained from the problem situation and area of concern, framework of ideas and methodology.

The definite model reflects the needs, desires, values and requirements of the civil engineering sector given the challenges of the rehabilitation assignment.

2.3.4 Framework design: systems engineering

In this part of the research, the transition is made to a hard systems thinking methodology where the aim is to design an intervention arrangement in the form of a conceptual framework of governance and coordination. For the design of this framework general systems engineering practice is used to structure system requirements, derived from the practical and theoretical inquiries that resulted in needs, desires and possibilities. Consequently, these requirements are transformed and embodied into a design – namely the conceptual framework itself. For the design of the conceptual framework, a three-dimensional engineering perspective is adopted that incorporates process, institutional and technical design perspectives (Herder, 2010 p.12).

Needs, desires, values and requirements

First, needs are defined as a lack of something wanted or deemed necessary. Second, a desires is defined as a strong feeling or aspiration of wanting to have something. Third, a value is defined as a property that needs to be to taken into account for something to be effective. Requirements specify how the needs, desires and values can be fulfilled. Brazier et al. (2018), distinguish between the following requirements:

- Functional: the purpose of a system (Why? For whom? Where?)
    - Functional requirements stipulate functions that a system must provide and are directly related to the mission of a system
- Behavioural: the way a system acts (How? When?)
    - Behavioural requirements specify desired behaviour of a design with respect to its mission, together with KPIs with which this behaviour can be determined
- Structural: the components of a system and their relationships (What?)
    - Structural requirements relate to components/subsystems of a system and their interdependencies
- Experiential: feelings, emotions, perceptions associated with a system (With whom? By whom? With what effect?)
    - Experiential requirements define the desired effect of a system on real people in the real world

Design

After the requirements are engineered, the system can be designed. Systems engineering is the process of translating requirements to design alternatives, conceptual designs, design implementation and design verification and validation. The design dimensions adhered to, according to Herder (2010), are process, institutional and technological designs for which the conceptual design functions as a synthesis. The

implementation of the design is an implementation of the conceptual framework onto the case study to address the challenges of the rehabilitation assignment.

2.3.5 Framework validation: qualitative data collection & analysis

Validation is the final step of the research to assess the viability of the framework by means of consensus in qualitative data. The validation of the designed framework is divided into two parts, namely, the qualitative data collection that was done by means of semi-structured expert interviews and the qualitative data analysis. The interview guide, list of interviewees, supplementary information and codes can be found in Appendix B. Furthermore, The interpretative and thus subjective nature associated with qualitative data reflects the transition from a hard to soft systems thinking methodology.

Semi-structured interviews

Before the semi-structured interview was held a short presentation was given. On the basis of the presentation, four questions and a few sub-questions were used to guide the interview. The intention of the interview was to find out the perceptions of experts in the civil engineering sector surrounding the rehabilitation assignment and to assess the viability of the framework. Therefore, the goal of the interview analysis can be split into two sub-goals: 1) to analyse the answer to the key questions posed during the interview and 2) to conduct a thematic analysis of the acquired data to provide a deeper understanding of the expert's perceptions with regards to the rehabilitation assignment.

Thematic analysis

Thematic analysis is the chosen method for qualitative data analysis (Braun & Clarke, 2006). A well-known and flexible method that is compatible with both inductive and deductive analysis styles. Braun & Clarke (2006) defined six phases of thematic analysis (table 2).

Table 26: Selected qualitative data analysis method: thematic analysis and its six phases adopted from Braun & Clarke (2006)

Six phases of Thematic analysis		
	Phases	**Description of analysis process**
1	Familiarise with the data	i) Narrative preparation, i.e. transcribing data ii) (Re-)reading the data and noting down initial ideas
2	Generating initial codes	i) Coding interesting features of the data in a systemic fashion across entire data set ii) Collating data relevant to each code
3	Searching themes	i) Collating codes into potential themes ii) Gathering all data relevant to each potential theme
4	Reviewing themes	i) Checking if themes work in relation to the coded extracts ii) Checking if themes work in relation to the entire data set iii) Reviewing data to search for additional themes iv) Generating a thematic map of the analysis
5	Defining and naming themes	i) On-going analysis to refine the specifics of each theme and the overall story the analysis tells ii) Generating clear definitions and names for each theme
6	Producing the report	i) Selection of vivid, compelling extract examples ii) Final analysis of selected extracts iii) Relating the analysis back to the research question, objectives and previous literature reviewed

According to, Braun & Clarke (2006) thematic analysis is a flexible method that can support both deductive and inductive approaches to analysis simultaneously. The coding process was mainly inductive and involved iteratively reading the transcripts and identifying interesting pieces of information. To be able to understand and interpret the data as such, the transcripts had to be read numerous times. The purpose of coding is to identify patterns within the data. These patterns in turn relate to themes with which an abstracted narrative can be constructed that tells a particular story. This narrative is dependent on the research interest of this thesis and thus is related to the relevant (sub) research question. At this part specifically, the core interest is to explore the viability of the developed framework. The assessment yields the validation of the approach and is expected to illuminate obstructions and difficulties of its implementation. Consequently, the analysis of the qualitative data also has a deductive character, given that the starting point is the validation of the designed framework.

Appendix B: supplementary material

B1. Explanation of Prisoner's dilemma and Stag hunt in game theory

Example 1: the prisoner's dilemma

The prisoner's dilemma was first introduced by Flood and Dresher. Suppose that two outlaws committed a crime together and got arrested for it. At the bureau, both of the outlaws are put in separate interrogation rooms such that the police officers can extract information and give the appropriate sentence. Now suppose that the two outlaws have no way of communicating with one another and can either choose to stay silent or to snitch their partner in crime. The police officers start the interrogation and offers a deal to both outlaws:

1. If you decide to snitch on your partner and your partner stays silent you are set free and your partner is sentenced to three years of imprisonment. However, if your partner also decides to snitch on you, you are both sentenced to two years imprisonment.
2. If you decide to stay silent and your partner stays silent you are both sentenced to one year of imprisonment. However, if your partner decides to snitch on you, you are sentenced to three years of imprisonment and your partner is set free.

The strategies (stay silent or snitch) and outcomes in either state of affairs can be displayed in a payoff-matrix.

		Outlaw 2
Outlaw 1	Stay silent	Snitch
Stay silent	(-1,-1)	(-3,0)
Snitch	(0,-3)	(-2,-2)

It appears that the outlaws are faced with a dilemma; remain silent or to snitch. The pareto-optimal outcome here is for both outlaws to remain silent since in this scenario they are both sentenced to only one year of imprisonment. However, given that the outlaws act rationally and in their self-interest and have no means of communication, they will always decide to snitch on their partner. As a result, both outlaws are sentenced to two years Therefore, given the constraints of the game, the pareto-optimal outcome, albeit mutually beneficial, is prevented from happening due to the strong incentive to snitch.

Now suppose that the outlaws had some way of communicating and incentivising to coordinate their strategies or had a rigid normative system which prevented them from snitching. In either case, both would have remained silent resulting in the pareto-optimal outcome. Hence, through establishing a coordination mechanism the collective action problem could have been overcome.

Example 2: the stag hunt

The stag hunt is a game first introduced by Rousseau. Suppose that two hunters live in the wild and need to go hunting to feed themselves. The hunters stumble on an animal trail; they decide to dig in and wait quietly for prey to pass as they only have one shot at catching a prey. Now suppose that two types of animals use the trail: stags and hares. Hunting a stag requires a team effort due to their size and provides three days' worth of food for each hunter. On the other hand, the smaller hares only provide two days' worth of food but can be caught by one hunter. Therefore, if one hunter is risk averse and decides to

hunt hare as it passes by the other hunter must join as well otherwise he will be left with no food. In the latter situation they will have to share the hare resulting in one day worth of food for each hunter.

The strategies (hunt stag or hunt hare) and outcomes in either state of affairs can be displayed in a payoff-matrix.

	Hunter 2	
Hunter 1	Stag	Hare
Stag	(3,3)	(0,2)
Hare	(2,0)	(1,1)

The hunters face a dilemma in which they either cooperate to achieve the highest payoff which implies hunting stag or to succumb to opportunism and hunt hare as it passes by which will only give a small payoff. It appears that in this game, two scenarios can unfold. Both hunters decide to remain at their post until a stag passes by and hunt the stag. In this scenario, the hunters each go home with three days' worth of food. As a hare passes by one hunter decides to leave the post and hunt hare, resulting in the other hunter to decide to hunt hare as well. Here the hunters each go home with only one day worth of food. Of the two possible scenarios, the pareto-optimal outcome is where both hunters decide to hunt stag. In contrast to the prisoner's dilemma, achieving the pareto-optimal scenario is possible. However, there still remains a possibility for the pareto-optimal outcome to be averted if one of the hunters decides to hunt hare when the opportunity presents itself.

Now suppose that the hunters possess a standardised trap only suited for hunting stag or the hunters engage in a contract where the goal of hunting stag is legally binding. In either case, the situation where hare is preferred over stag is prevented, thus always resulting in the pareto-optimal outcome. Again, introducing a coordination mechanism is able to prevent opportunism and allows the collective action problem to be overcome.

B2. Definition of a participatory system: sources consulted

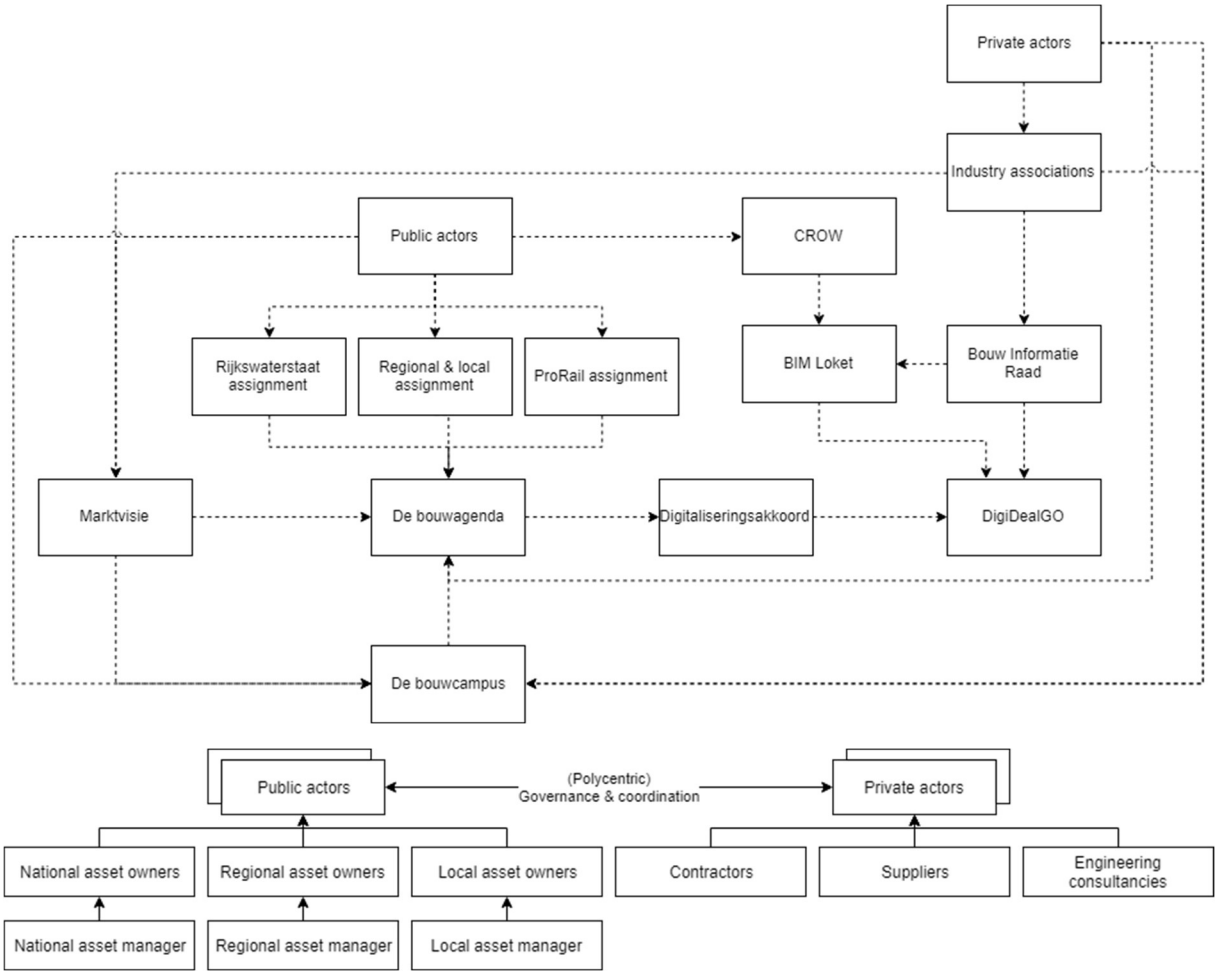
Table 27: Definitions of participatory systems

Definitions of participatory systems	
Source	**Definition**
Participatory systems initiative	Participatory systems are large-scale sociotechnical systems enabled by technology/connectivity, coordinating and orchestrating self-organisation, designed to provide individuals and organisations the ability to act and take responsibility in today's networked society.
Rezaee et al. 2013	Participatory systems are designed to support the participation of social entities by coordinating between and within social entities and technical systems. In particular, coordinating their interaction and organisational structure is a major concern. The primary focus of participatory systems design is on sociotechnical large-scale networked systems such as supply networks or electricity grids.
Rezaee et al. 2015	A participatory system is a socio-technical system in which actors participate to accomplish the system's mission. Participation is related to a larger whole and participants are empowered to act accordingly. Participants engage in a participatory system. They contribute to a system mission and take responsibility according to their accepted roles in the system. Participatory systems values (trust/integrity,

	empowerment/autonomy, and engagement) are essential for accomplishing the mission. Coordination and managing relations is crucial to participatory systems.
Van Kooten et al. 2018	Participatory systems in today's networked society are characterized by the potential, scale and speed of distributing information and communication that technology can provide. Participatory systems are sociotechnical systems designed to support participation through engagement, empowerment and trust, enabling participants to act and take responsibility for their actions.

As can be derived from the multiple definitions (table 27), participatory systems are socio-technical systems that rely on communication and coordination mechanisms enabled by (information and communication) technology. As such, to stimulate engagement, self-organisation and distribution of information between actors. A successful participatory system enables participation through emphasising on the values of trust, integrity, autonomy and empowerment. All in all, a participatory system aims to contribute to accomplishment of the system's mission within the broader context it is part of. Referring to the large-scale distributed and networked socio-technical system the participatory system is embedded in, consisting multiple social and technical systems.

B3. Relational diagram of actors, associations, platforms and initiatives



B4. An estimation of the costs of the rehabilitation assignment using proxies

In total €9.5 billion is allocated to infrastructure and water state in 2019 (Rijkswaterstaat and ProRail). For the regional and local infrastructure managers, a total of €7.6 billion is allocated to their infrastructure management activities for 2019 (CBS statline).

- Waterboards allocated €1.5 billion;
- Provinces €2.2 billion;
- Municipalities €3.9 billion.

Thus, the budget of the public actors adds to €17.1 billion. It should be noted that this amount includes *all* of the infrastructure related activities thus it is not exclusive to civil infrastructure and engineering structures. Assuming that the €105 billion can be equally divided over the 15 years, the annual budget for the civil infrastructure portfolio is estimated at around €7 billion. Implying that an estimated 41% of the total infrastructure budget in 2019 is allocated to the rehabilitation of civil infrastructure and civil engineering structures. To give an accurate example: Rijkswaterstaat's budget for the management and maintenance of civil engineering structures in 2019 amounts €1.4 billion.

Rijkswaterstaat and McKinsey (2019) provide an estimation of the distribution of project offering between Rijkswaterstaat and other public actors in the period of 2012 and 2018 (figure 20). The estimation indicates that 35% of all projects are offered by Rijkswaterstaat and the remaining 65% are offered by other Public actors. Assuming that this distribution holds for 2019 and is generalisable for rehabilitation projects, we can use this distribution to estimate the total annual costs for the rehabilitation of civil engineering structures. Rijkswaterstaat's budgeted costs equals €1.4 billion and corresponds to 35% of the total budget. Therefore, the other 65% approximates to €2.6 billion. Adding those two gives us an estimation of approximately €4 billion for the rehabilitation of civil engineering structures: approximately 57% of the total annual costs of the civil infrastructure portfolio.

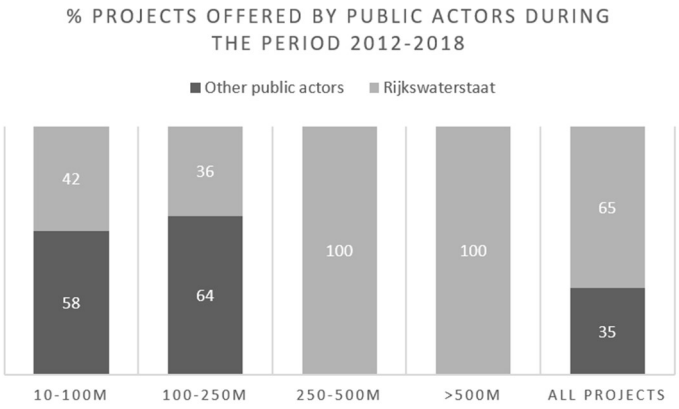


Figure 19: Percentage of projects offered by public actors during the period 2012-2018 indicated ranges are in Millions of euros (source: RWS & McKinsey, 2019) The data collected by the source only includes projects of which the price was known (corresponding to 30% of the total projects)

B5. Process management design principles

The following list provides an overview of those four principles and suggests relevant and implementable process elements (de Bruijn et al., 2010):

1. *Openness* implies that the intitiators do not take unilateral decisions but adopts an open attidute where other actors are empowered to contribute to steering the decision making and thus put forth issues (individual intersts) on the agenda.
    a) *Involve all relevant actors:* In the process, the participation of all relevant actors is necessary. The involvement of the actors should be phased according to the rationale of the stage and round.
    b) *Process and design transparency:* The process and its design should be transparent for all actors such that it stimulates collective action due to integrity.
2. The *protection of core values* should ensure that the process is a trustworthy environment in which the core values of participating actors are protected. This enables the actors to commit and parttake in the programme process and expose their vulnerabilities.
    a) *Protect core values of actors:* both public and private actors have different values and should be protected in the process this facilitates a level playing field and invites for participation.
    b) *Park sub-decisions:* subdecisions that result in an impasse should be parked, the impasse might be resolved in a later phase in the (design) process.
3. The principle of *progress* should ensure that sufficient momentum is generated in the process such that the decision-making yields satisfactory outcomes.
    a) *Stimulate early participation:* provide attractive starting conditions and quick wins in early stages of the process to stimulate participation in an early stage of the process.
    b) *Strive for high participation:* progress can be stimulated when the process involves multiple actively contributing actors.
    c) *Process governance:* a governance body that is able to steer the process to reduce conlfict and overcome impasses.
4. *Substance* refers to the requirement that the process should have a sufficient content that are appealling to the actors such that decision-making is stimulated.
    a) *Involve experts:* involving expert knowledge such as universities to provide objective information and infuse state-of-the-art knowledge in the process.

Appendix C: Interviews

C1. Interview setup and guide

The interviews were conducted according to a short introduction through a presentation. The slides of the presentation (in Dutch) are provided in APPENDIX C2. First, the problem is presented: the upcoming complex rehabilitation assignment of bridges and viaducts in the Netherlands. In order for this assignment to be successfully tackled a productivity increase needs to be realised within the Dutch civil engineering sector that consists of multiple autonomous public and private actors, each with their own interests, that are directly or indirectly interdependent of one another. Second, criteria that improve productivity are introduced (table 28).

Table 28: Proposed criteria that facilitate the productivity increase within the Dutch rehabilitation assignment

Criteria that facilitate the productivity increase	
criterium	**description**
Standardisation	The standardisation of processes, materials and techniques and technologies.
Digitisation	The transition towards the utilisation of digital technologies. Such as Building Information Modelling and sensor technologies in project and monitoring processes. But also the facilitation of better communication.
Innovation	Innovation in processes, technologies and institutions.
Knowledge development and sharing	The development of knowledge within projects and the sharing of this knowledge across project and organisational boundaries.
Resilience/elasticity	The grip on the situation within the context of projects and the broader rehabilitation assignment.
proactivity	The emergence of initiatives orchestrated by private actors without direct involvement of public actors.

Third, three alternative approaches are presented with which the rehabilitation assignment can be executed. These were differentiated as a project, portfolio and network approach. Each approach is characterised by the connection (or disconnection) between actors and projects within the rehabilitation assignment. Figure 20 depicts this as a wall between actors involved in different projects. More specifically, as the figure attempts to visualise with simplicity, a project approach considers a project as a unique and single endeavour where there is little to no interface between the various projects and actors. Subsequently, a portfolio approach refers to the bunding of similar projects within the directory of a public actor to the extent that which these projects are considered in relation to one another. Here projects within the portfolio are managed as a collective whereas there is little interface between other portfolio's or projects of other public actors. Finally, the network approach considers projects and actors as connected with one another in a complex web of networks that are formed on the basis of shared characteristics. These characteristics can be related to the type of project, functional and-or characteristics of the artefacts, and the social network formed between public and private actors.

Figure 20: Three visualisations of the alternative approaches presented in the validation interview

Fourth, given the ambition of the sector in the context of the complex rehabilitation assignment, each approach was assessed according to the expected the productivity increase. This implied that for each approach the above mentioned criteria were assessed. As a result of this assessment, descriptive factors emerged that determined the relative impact on the productivity increase of the Dutch civil engineering sector. These factors were derived from the case study and research conducted in this thesis and presented to experts from the Dutch civil engineering sector for validation and reflection. Moreover, the factors are presented in table 29 where each factor is assigned a (+), (0) or (-) representing the values positive, neutral and mediocre respectively. From this assessment it appears that the network approach is expected to provide the highest contribution to the required productivity increase in the Dutch civil engineering sector, followed by the portfolio approach and the project approach after that.

The explanation behind this ranking is the fact that the diffusion of innovation and knowledge and the adoption of common standards and (digital) technologies is highest when actors and projects are interconnected. Such an interconnection is expected to be highest in the network approach and lowest or even non-existent in the project approach. The portfolio approach can be interpreted as a network consisting of many disconnected smaller components (i.e. batches of projects).

From this line of reasoning, when there are no direct connections (dependencies), standardisation can only be enforced from a top-down mechanism. Only within network components – i.e. nodes in a network (such as projects and actors) that are connected with one another – standardisation may emerge from a bottom-up mechanism, for example the incentive to be interoperable within a network. Similarly, the full potential of digitisation, as described in the case study, can only be achieved when the sector as a whole embraces those innovative technologies and agrees upon common interfaces – e.g. the deployment of sensor technology, BIM, data analytics and others mentioned in the case study. On the contrary, in project approach, the only assurance is better interoperation within the project; this also holds for portfolios. Another criterium is innovation which plays an important role in the increase of productivity within the rehabilitation assignment. Innovation may refer to process, technological and institutional innovations and innovations are diffused widespread within the sector. This requires clear diffusion channels and certainty on return on investment; otherwise innovation does not spread nor happen. In line with the diffusion of innovations is the development and sharing of knowledge in the sector to bolster productivity and competence. Another criterium identified to contribute to the productivity increase of the rehabilitation assignment is the total grip on the situation and thus the assignment's resilience to events and uncertainties. Also here, the more connectivity within the assignment the more awareness there is for anomalous situations and competence for compensation. This is reflected in the project, portfolio and network approach where more connectivity is expected to lead to better decision making. Last but not least, proactivity within the assignment is an important contributor to the productivity. Taking initiative and being cooperative is a trait that should be adopted widespread within the civil engineering sector and specifically among private actors. However, this requires appropriate incentives to be in place. The nature and effects of the underlying incentives vary per approach.

Table 29: Factors assessing the expected productivity increase for each approach within the sector according to the six criteria defined in table 28.

Factors explaining the 'behaviour' of criteria per approach			
Criteria	**Project approach**	**Portfolio approach**	**Network approach**
1. Standardisation	Top-down initiated by public authorities (0)	Top-down (external to portfolio), Bottom-up (internal to portfolio) emerging from partnerships (0)	Bottom-up phenomenon due to the incentive to remain interoperable (+)
2. Digitisation	Interoperability within project (-)	Interoperability within portfolio (0)	Connectivity among participants (+)
3. Innovation	None due to high risks and uncertainty in Return on Investment (-)	Plentiful within portfolio due to long term certainty, little external to portfolio (0)	Many depending on the network properties such as willingness to share (cohesiveness) (+)
4. Knowledge development and sharing	Information retention (-)	Knowledge development and sharing across projects within the portfolio (+)	Continuous knowledge sharing and emergence of network effects (multiplication of knowledge) (+)
5. Resilience/elasticity	Risk management in projects (0)	Shared risk, continuous improvement within portfolio (0)	Awareness within the sector due to self-organisation around subjects (+)
6. Proactivity	Low profitability and awarding the contract according to MEAT disincentivises taking initiative (-)	More initiative and focus on quality due to performance measurement and certainty (0)	Sector participation, collective action and focus on quality due to reputation in the network (+)

Fifth, after the factors are explained and the comparison between the different approaches is made, the interview is started. The interview is semi-structured implying that further questioning may take place where necessary. The structure of the interview consists of four questions that reflect on the aforementioned information – criteria, approaches, factors and evaluation. The questions are:

1. Are the criteria meaningful?
    a. What criteria are most important?
    b. Are there any other criteria of importance that have not been mentioned?

2. Do the three approaches presented in this presentation give a good overview of the possible approaches?
3. Are the factors that have been associated with the approaches and criteria respectively correct?
    a. Could any of them be different?
    b. Are they complete?
    c. What other factors, in your opinion, play an important role?
4. According to you, which approach is most feasible and why?
    a. With what approach do you believe the rehabilitation assignment to be feasible?

The interview based on these questions is recorded and transcribed (see Appendix B4).

B2. Presentation slides

When conducting the interviews on the basis of the interview setup and guide presented in Appendix B1, a PowerPoint presentation used. The PowerPoint presentation used in the interviews is in Dutch. The choice for the Dutch language is for convenience purposes such that the interviewees are more comfortable. The slide deck consists of in total 10 slides (figure 21 until figure 30). The actual content used in the interview is presented in 4 slides (figure 24 until figure 28). The questions used in the interview are presented in figure 29.

Figure 21: Slide 1 out of 10 of the presentation.

Figure 22: Slide 2 out of 10 of the presentation.

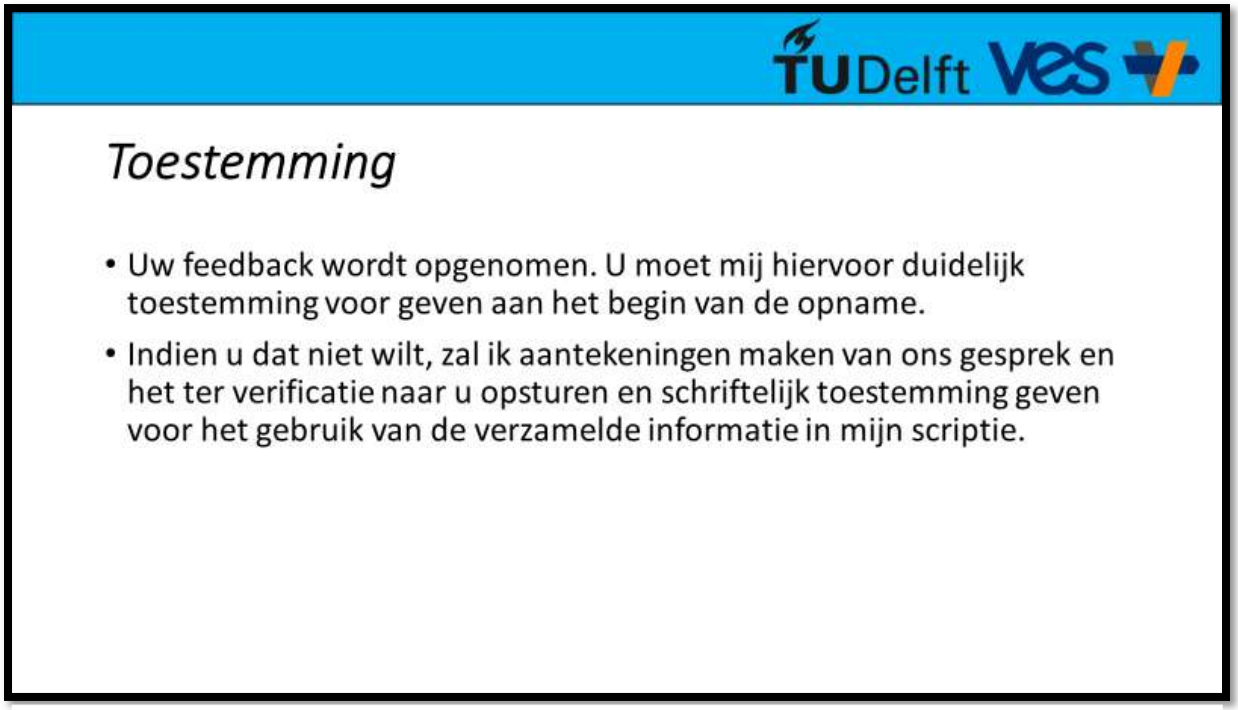


Figure 23: Slide 3 of 10 of the presentation.

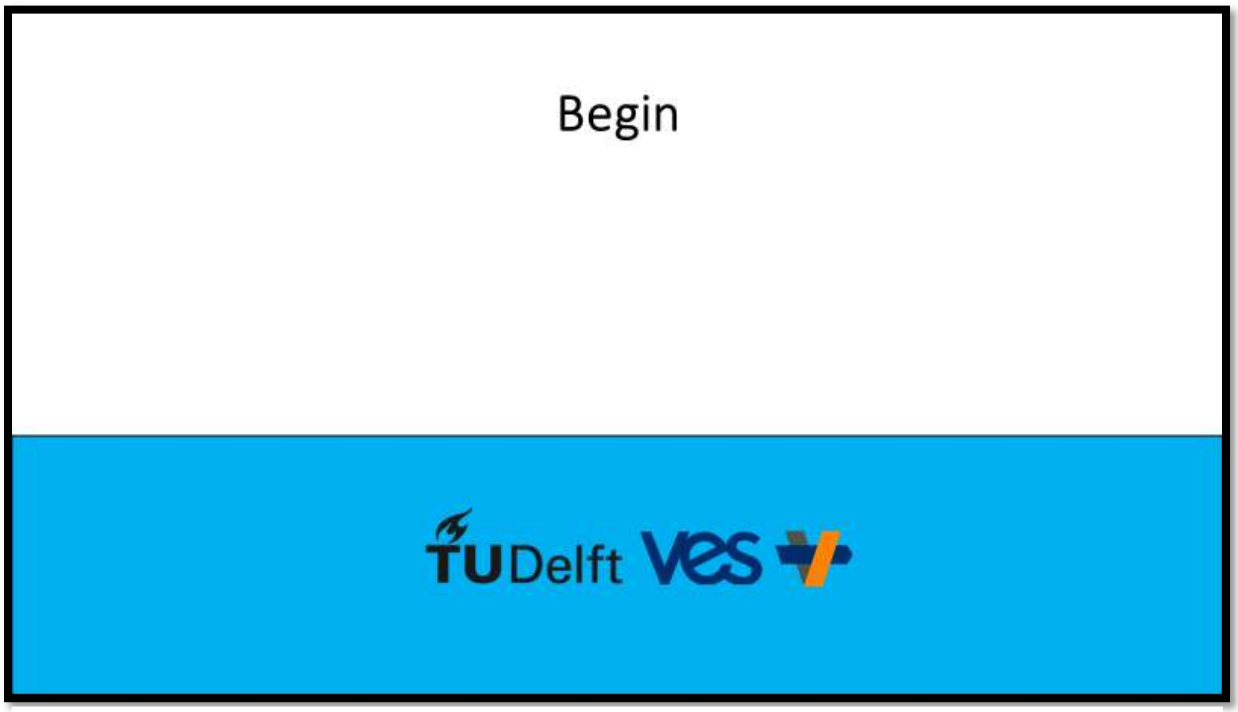


Figure 24: Slide 4 of 10 of the presentation.

Figure 25: Slide 5 out of 10 of the presentation.

Figure 26: Slide 6 out of 10 of the presentation.

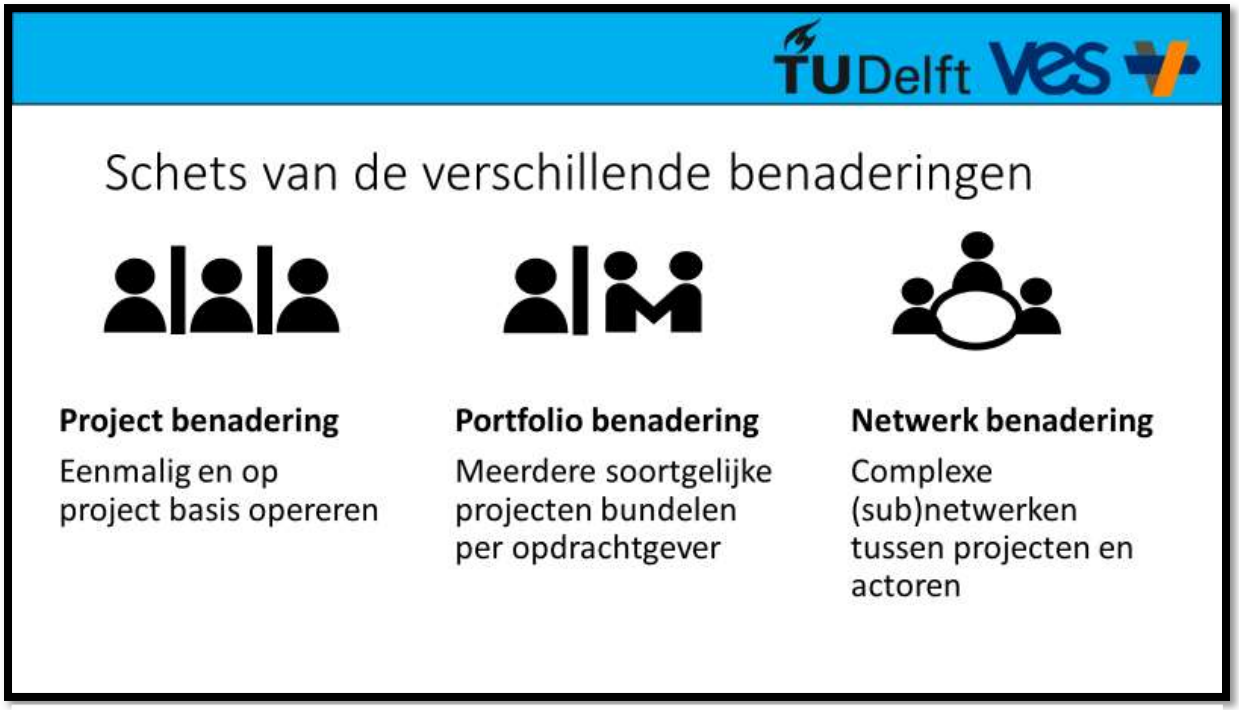


Figure 27: Slide 7 out of 10 of the presentation.

TUDelft

Drie benaderingen

Maatstaf: productiviteitsgroei in de sector
Rangschikking: (- matig, 0 neutraal, + positief)

Criteria	Project benadering	Portfolio benadering	Netwerk benadering
1. Standaardisatie	Top-down (0)	Top-down (extern), Bottom-up (intern) (0)	Bottom-up (+)
2. Digitalisering	Interoperabiliteit binnen project (-)	Interoperabiliteit binnen portfolio (0)	Connectiviteit (+)
3. Innovatie	Niet tot weinig (-)	Veel intern portfolio, weinig extern (0)	Veel a.d.h.v. netwerk eigenschappen (+)
4. Kennisopbouw en deling	Informatie retentie (-)	Kennis opbouw en deling over projecten heen binnen portfolio (+)	Continue kennisdeling en netwerk effecten (kennis vermenigvuldiging) (+)
5. Veerkracht	Risicobeheersing project (0)	Continue verbetering binnen portfolio (0)	Bewustzijn in de sector door zelforganisatie rondom onderwerpen (+)
6. Pro-activiteit	Lage winstmarge en EMVI zorgt voor weinig initiatief; principe van U vraagt, wij maken (-)	Meer initiatief en focus op kwaliteit door prestatiemeting en zekerheid (0)	Sector participatie, meer actie en focus op kwaliteit door reputatie (+)

Figure 28: Slide 8 out of 10 of the presentation.

Figure 29: Slide 9 out of 10 of the presentation.

Figure 30: Slide 10 out of 10 of the presentation.

B3. Conducting the interviews

This Appendix presents information regarding the interviews. The interviews are transcribed however the transcriptions are not included in the main thesis document but can be released upon request. Any company names or names of third-party individuals that were mentioned in the interview are anonymised in the transcription. The interviewee list is presented in the table below (table 30). Noteworthy to mention is that the interviewees are respected and have authority within their organisation and within the sector. Even so, each interviewee has its own perception on the subject of the rehabilitation assignment. This has to do with their current position and the interaction of the interviewee with the subject.

Table 30: Overview of interviewees, including their affiliation and interview date.

Interviewee list					
#	**Interviewees**	**Role**	**Organisation**	**Date**	**Permission**
1	Pjotr Mak & Emile Heijmans	(Project) Management	VolkerRail / VES	12-12-2019	Yes
2	Henrie van Buuren	Consultant and management	Self-employed	16-12-2019	Yes
3	Lindy Molenkamp	Director	Province Noord-Holland	20-12-2019	Yes
4	Maurice van Rooijen	Consultant and owner	Rijkswaterstaat & Jonge Geesten	13-01-2020	Yes
5	Roland Dijkhuizen	Consultant	Arcadis	16-01-2020	Yes
6	Frank van der Vaart	Head of department engineering services	Municipality of Utrecht	24-01-2020	Yes
Total interviewees: 7					

B4. Transcribing and coding guide

The language spoken in the interviews is Dutch whereas the transcription is translated into the English language. The information content is the same yet the word choice was adapted to fit the translation. In each transcription the interviewer is referred to as ‘interviewer’ whereas the subject is referred to as ‘interviewee’. In case of an interview consisting of multiple interviewees, the distinction will be made between ‘interviewee 1’, ‘interviewee 2’ and so forth. Furthermore, in the beginning of the recording and in line with research-ethics, permission has to be given to use the contents of the interview in this research.

For the extraction of meaningful and useful information, the interview transcripts are coded in an inductive to support the analysis process. Coding involves the discovery of important pieces of information that are labelled in a generic form. By bundling the codes in categories themes can be generated. From these themes and their interpretation, a meaningful narrative that is grounded in the qualitative data emerges. Codes are the lowest unit in qualitative analysis that represent subjects found in the transcripts. In turn, the codes are categorised into the respective categories – for example the criteria, approaches and factors.

The transcript is organised according to the interview number, question number and line. A line is referred to as I#Q#L# - for example interview 1 question 1 line 5 can be described as I1Q1L5. A ‘line’ that is referenced in a code may hold multiple codes as it may consist of multiple sentences.

The main objective of the coding and analysis process is to provide the answers to the posed questions and to add useful context to these questions. The answering of those questions will function as the validation of the research conducted in this thesis. Thus, the qualitative research through interviews holds two purposes. Firstly, as answers to the question and secondly to explore and induce contextual information from the transcription. Contextual information can be considered as information that explains or introduces additional information relevant to the research questions. The resulting code book and generated themes are presented in Appendix B5.

B5. Code book and themes

B5.1 Identifying relevant codes

As a product of the second phase of the thematic analysis method the transcriptions are coded. The following table lists and describes each relevant code identified from the data items (interviews).

Table 31: Code book of the coded transcriptions including description.

Code book: list of identified code from transcripts		
No.	**Code**	**Description**
1.	**Create sense of community**	Develop a sense of community within the sector that stimulates participation and the development of relations among actors
2.	**(Re-) incentivisation**	Introduce new or revisit existing incentives to stimulate the transition toward a more productive civil engineering sector
3.	**Stimulate innovativeness**	Innovation and the diffusion of innovations needs to be stimulated and facilitated
4.	**Relevance of specific innovations**	Innovation is a vague term that requires to be redefined and more pragmatic (contextual). Yet innovation is necessary with regards to realising the productivity growth
5.	**Standardisation requires governance**	The emergence and enforcement of standards
6.	**Criteria open up new opportunities**	The defined criteria and combinations thereof result in new opportunities that contribute to the productivity growth
7.	**Means to achieve goals set in the rehabilitation assignment**	Suggested measures with which the rehabilitation assignment is expected to be completed.
8.	**Improve and increase collaboration**	The shift towards a more collaborative sector in order to be able to cope with the increasing demands of the rehabilitation assignment
9.	**Uncertainties towards new approaches**	The uncertainties that revolve around approaches that deviate from the standard project oriented approach
10.	**Criteria for productivity growth are interrelated**	The mentioned criteria are combinable and interrelated
11.	**factors that hamper productivity growth**	Productivity growth is hampered by existing factors

12.	**Sector macroscopic trends force change**	Exogenous movements that influence the civil engineering sector and thus forces it change
13.	**Presented approaches are representative**	The project, portfolio and network approaches represent reality
14.	**Perceived difficulties in the implementation of new approaches**	The implementation of new approaches are faced with resistance that need to be overcome
15.	**Transparency**	Transparency and openness is a key element for collaboration, trust and fruitful networks
16.	**Approach integrability**	The three presented approaches are indicated to be combinable with one another
17.	**Business model reform**	The transition towards a more productive sector requires new business models to be exploited
18.	**Institutional renewal (property & decision rights)**	Current in-place institutions need to be swapped with more adequate and contemporary models suitable for future challenges
19.	**Network approach facilitates change**	Due to the implementation of networks change within the sector is facilitated
20.	**Incompatibility of contemporary culture**	The current culture of the civil engineering sector is incompatible with change and new approaches
21.	**Cultural paradigm shift**	In order for the civil engineering sector to adopt new ideas, a cultural paradigm shift is required that allows the sector's transformation
22.	**Increasing sense of urgency**	Increasing the sense of urgency of the rehabilitation assignment stimulates the sector to accelerate change
23.	**Benefits of portfolios**	The introduction of portfolios are considered to be contributing to the productivity of the sector
24.	**Institutional renewal is easier with portfolios than networks**	Portfolios are more compatible with current institutions and thus easier to adopt than the proposed network approach
25.	**Government should initiate change**	The government should initiate change through stimulating and facilitating the market to become more productive
26.	**Organisations need to adapt**	In order for the assignment to be realisable organisations within the civil engineering sector must adapt
27.	**Gradual implementation of networks**	For a network approach to be successfully implemented it requires a careful and stepwise implementation
28.	**Increase social responsibility**	The social responsibility of the civil engineering sector should increase such that sustainability and circularity are accepted

29.	**Current project-centric approach**	The project approach is the current most frequently and standard approach utilised by the sector
30.	**Dysfunctionality of current approach**	Accounts that the current approach – i.e. the project approach – is dysfunctional in achieving the required productivity growth and is generally considered as ineffective
31.	**Network approach is desired**	Accounts indicating that a network approach is desired
32.	**Portfolio approach will not change the sector's culture**	The portfolio approach albeit a contributor to productivity is not considered to adequately influence the sector's culture
33.	**New generation will bring change**	The new generation entering the labour force are believed to realise change
34.	**Inclusive sector for new entrants**	New entrants can be innovative and penetrate current practices as such disrupt the industry and deliver insights from other industries
35.	**Information diffusion**	Stimulate knowledge development and sharing within the sector and across actors
36.	**Shake up current practices**	Current practices within the sector need to be redesigned such they become future proof
37.	**Compliance of rules and regulations**	The rules and regulations themselves do not obstruct change rather it is the incompetence or unwillingness of the sector
38.	**Obstacles in rules and regulations**	Certain obstacles in rules and regulation should be overcome if the sector desires to realise a paradigm shift
39.	**The contribution of pilot projects**	Pilot projects are considered as accelerators of innovation and are pivotal for collaboration contributing to the transition to a new paradigm
40.	**Importance of 'the individual'**	The individual and human aspect is one of if not the most important aspects within the rehabilitation assignment
41.	**Expressed need for a system disruption**	For the rehabilitation assignment a system disruption is necessary
42.	**Distribution of power among actors**	Within the civil engineering sector dominant and sub-dominant actors exist that each have their own position and power
43.	**Sector readiness**	The readiness of the sector to realise the transition either culturally or technologically
44.	**More government regulation**	For the rehabilitation assignment to be accomplished more regulations should be implemented
45.	**Lack of competence and insight**	The sector is lacking competence and insight to be able to realise the transition toward a more productive and sustainable sector

46.	**Redefine roles within the sector**	The roles within the sector should be redefined such that they suit the new system of the sector

B5.2 Constructing relevant themes

Given the abovementioned codes, relevant themes are constructed that are able to work together to tell a particular and overall story in accordance with the research questions. More specifically, the goal of this part of the research is to validate whether the conceptual framework of governance and coordination satisfies the identified requirements relevant to the rehabilitation assignment. In total four themes were identified these are presented in table xx.

Table 32: Themes that were identified through the thematic analysis of the interview transcripts. The table lists and describes the themes that emerged through collating the codes presented in table 31. (Source: Author's own deliberation)

		Identified themes	
#	**Theme**	**Description**	**Collated codes**
1	**Organisational changes within the sector**	For the challenges in the rehabilitation assignment to be addressed effectively, organisational changes are required within the sector. More specifically, institutional renewal leading to new incentives, business models, and rules and regulation wherein the traditional roles between public and private actors are redefined. Therefore, by reorganising the sector in such a way, a more collaborative sector is expected that can facilitate more innovation, standardisation, digitisation and knowledge development and sharing. As such, practices are reformed such that the desired networked approach can be implemented.	• (re-) Incentivisation • Institutional renewal • Business model reform • Reform current practices • Redefine roles within sector • Stimulate innovation • Improve & increase collaboration • Network approach is desired
2	**Firm grip of project-centrism**	The project approach is the current approach. However, the project approach is dysfunctional and cannot realise the rehabilitation assignment. Yet, still, there are uncertainties and perceived difficulties towards new approaches and obstacles in the rules & regulations, causes the sector to be stuck in the current status quo. The aforementioned barriers negatively impact the sector's readiness to adopt new approaches.	• Current project approach • Current approach is dysfunctional • Perceived difficulties in new approaches • Obstacles in rules & regulations • Uncertainties towards new approach • Sector readiness
3	**Cultural paradigm shift**	In order for the sector to break free from project-centrism, a system disruption is necessary that is able to overcome the barriers such as individual interests and facilitate collective action. However, contemporary culture is incompatible with new approaches. Therefore, a cultural paradigm shift	• Means to accomplish assignment • Network approach is desired • Incompatibility of contemporary culture

		required where the focus on community and collaboration, increased sense of urgency, social responsibility, openness to new entrants and transparency is realised.	• Expressed need for system disruption • Cultural paradigm shift (rename) • Inclusive sector to new entrants • Sense of community • Increase social responsibility • Increase sense of urgency
4	**Transition path towards a network approach**	Government should take initiative in the rehabilitation assignment by incentivising private actors to change. Although a network approach is desired, its gradual implementation should be facilitated and pilot projects need to be facilitated. Effective strategies that harness the interrelatedness of the identified criteria for productivity growth should be leveraged.	• Contribution of pilot projects • Gradual implementation of network approach • Information diffusion • Transparency • Importance of the individual • Involve new generation • Relevance of specific innovation • Government should take initiative • Stimulate innovation • Compliance of rules & regulation • Network approach facilitates change • Approach integrability • Criteria for productivity growth are interrelated & open up new opportunities • Involve new generation • Increase & improve collaboration

B5.2 Relationship between themes

To break free from the firm grip of the project-centric approach and shift towards a network approach, a cultural paradigm shift is needed. However, a network approach is too dissimilar and requires a transition path (phased/multi-stage approach) for which governments need to take initiative. Within this

transition, besides a cultural shift, organisational changes should be realised that are able to support a new (networked) approach.

B6 Direct analysis of the interviews

This section in the Appendix provides a detailed analysis of the direct answers given by the interviewed experts. The four questions attempted to find out:

- Whether the criteria are meaningful, which are important and if any are missing;
- Whether the three approaches are representative and if there are any other approaches;
- Whether the respective effects of a specific approach on the criteria are correct;
- And finally, which of the presented approaches is most feasible and why.

B6.1 Reflections on the criteria for productivity growth

Meaningfulness and importance of criteria

All experts expressed the meaningfulness of the presented criteria, and are thus believed to contributing to the necessary productivity growth. But it was also mentioned that they were not exhaustive – either explicitly or by suggesting the importance of other criteria.

> *"Mak: I think all of the criteria are able to contribute to realising the necessary productivity growth.*
> *Heijmans: Yes, but I am questioning myself whether they are exhaustive." -(I1Q1L2-3)*

Upon asking which of the criteria listed in the presentation were most important, the predominant responses of experts were innovation, digitisation, knowledge development and sharing and standardisation. The importance of resilience and proactivity were each mentioned by only one expert. Figure 18 visualises the number of explicit mentions of each criterium in response of the first question.

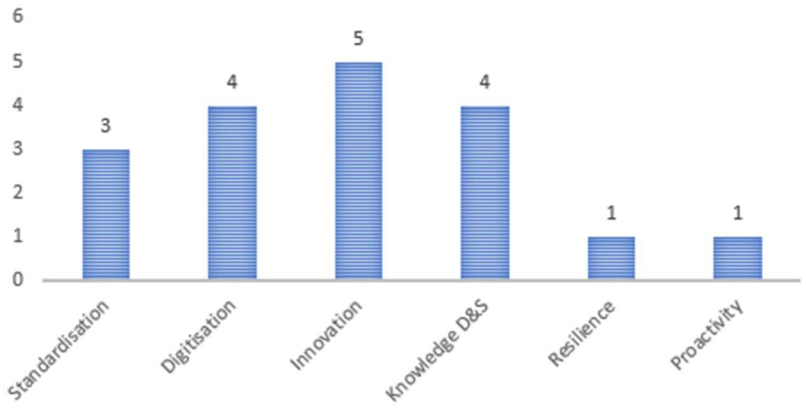


Figure 31: Histogram of number of mentions per criteria with respect to their importance (source: Q1 of interview transcripts, made in MS Excel)

By looking at the histogram, it becomes clear that innovation is found to be most important, digitisation and knowledge development have shared second place followed by standardisation. This ranking of criteria matches the findings of the desk and action research of this research and is expressed in chapter 4. Criteria that were left out referred to the obstacles that need to be overcome and are related to cultural and institutional characteristics of the civil engineering sector. Quite interestingly, the experts were not reluctant to address their importance as we will further uncover in the next parts of the analysis.

The problem with innovation

Although innovation came out on top, it is considered as a rather unambiguous criterium. Since, according to many experts, innovation has become an umbrella term that has lost its meaning as it can be applied to everything.

> *"van Rooijen: […] You mention innovation as a criterium, but innovation is a umbrella term under which almost everything can be placed." –(I4Q1L2)*

More specifically, when referring to innovation, it should include rules and regulation due to the fact that current guidelines and codes do not match the needs of the rehabilitation assignment and thus are unable to facilitate innovative solutions that allow for new materials and faster construction processes.

> *"Molenkamp: […] What I also think is important, which you might be able to put under the criterium of innovation, is the problem that we use rules and regulation of the past to test the future. If you consider this to be part of innovation then in my opinion related to knowledge development and sharing will need to include the assessment whether the guidelines and codes are suitable for the future situation and should there be enough room for new innovative solutions such as new materials (e.g. composites), new construction processes that can be a lot faster. In all those points we observe that obstacles occur in the existing yet outdated rules and regulation." –(I3Q1L6)*

Furthermore, besides rules and regulation, cultural innovation was mentioned and perceived to be an important interpretation of innovation since, according to van Buuren, the biggest bottleneck that hampers productivity growth is culture not technology.

> *"van Buuren: If with innovation you also imply the cultural innovation. Then I think that is the most important one. Because that is where the bottleneck is. The bottleneck is not technical; the bottleneck is cultural." –(I2Q1L18)*

The fact that innovation has lost its meaning in the civil engineering sector and rehabilitation assignment is also reflected in the diverging responses with regards to innovation. Institutional (referring to rules & regulations) and cultural innovation are justified terms, but do not contribute to the expected level of pragmatism in the debate.

> *"Mak: Innovation has become such a container term where I am starting to wonder what it is that you are trying to say exactly. I would indeed say, as you have said, we have innovation regarding rules and regulation which is very important but is not often immediately associated with the term innovation. Innovation in collaboration. Innovation on processes. Innovation on mechanisation." –(I1Q1L15)*

Therefore, either being more explicit on the 'type' of innovation or defining new terms might resonate better with the broader audience for whom the concepts apply.

Digitisation and standardisation as facilitators of innovation

In line with the aforementioned, it appears that especially innovation was often seen close to, and perhaps even interchangeable with, digitisation and standardisation. This was especially reflected by van Buuren.

"van Buuren: […] Perhaps the first two criteria are unnecessary since they can be positioned under innovation. The different types of innovation have not been mentioned separately.

Interviewer: You are talking about process innovation?

van Buuren: No, monitoring and the use of drone technology for instance. Since you mention digitisation.

Interviewer: Ok, so you can interpret such innovations as a derivative of perhaps a combination of the criteria mentioned in this presentation?

van Buuren: Yes, so for all that matters to me, the first and second criteria need not be mentioned explicitly." –(I2Q1L2-6)

Thus, even though innovation is overall considered to be most important, together with digitisation and standardisation these criteria are generally perceived to be interrelated to one another.

"Mak: a criterium that I miss if you mention digitisation is industrialisation. You could also argue that standardisation leads to – and here you see the interrelatedness between the criteria – industrialisation as you will be increasingly able to construct with prefab (pre-fabrication assemblage)." –(I1Q1L11)

Here Mak indicated that the cohesion between digitisation and standardisation may lead to another criterium for productivity growth, namely, industrialisation. In the same line of reasoning another expert provided an example that indicated the interrelatedness of digitisation and standardisation leading to what he perceived to be an innovation, namely, automation.

"Dijkhuizen: For example, I am involved in a standardisation project where we are constructing a OTL (Object Type Library) that contains all standard measurements and sizes of objects such as roads, signals, barriers and signs. Consequently, you do not have to do anything besides pressing a button that generates a design automatically. This helps a lot and digitisation complements this nicely. It is also an innovation." –(I5Q1L4)

Taking the latter two data extracts into consideration, the criteria standardisation and digitisation seem to be interrelated. Therefore, strategies that combine criteria are considered to be more effective in realising productivity growth since they lead to innovations such as automation and industrialisation. An example where the need for such strategies becomes apparent, is one where institutional and cultural innovation of the organisation is not well integrated with digitisation.

"van der Vaart: Digitisation, I think there certainly is an improvement that can be made. For instance the developments of 3D and BIM enable us to build mistake-proof designs since you are able to make certain decisions at an early stage of the design. Or, whether you want to design part of it yourself (contracting authority) and then pass it on to a contractor, that definitely ensures that digitisation is necessary. But I do notice that the public actors (government) is causing for much delay. A BIM model for instance does not fit within our asset management systems. So what is the current utility of such a digital technology for an asset manager (in this case a contracting authority)?

Interviewer: You notice on the contracting authority side that platforms such as CROW and BIM-loket are working on BIM technology. Does this benefit you?

van der Vaart: Well we do ask for it in our procurement (project specification) and we include it in our designs. But we do notice that at a certain point, us as a contracting authority, obtain

a BIM model but subsequently do not know how to save it. And are our systems able to deal with such a technology (software)? Do we have a central place for this? That are questions that we are currently trying to solve. Utrecht is busy with a 3D model of the city. But who is responsible for that? The asset manager? The IT department that manages the data and such? So those are questions that need to be tackled from the contracting authority perspective.

Interviewer: On what organisational level do these issues (questions) emerge? And Is it at the director, management or operational level where most delay is caused?

Van der Vaart: Good question. I think at the director level as they do not necessarily see the added value and impact of digitisation yet. We can start pushing for change bottom-up when we feel that a certain digital technology should be embraced. But in the IT environment of a municipality such as Utrecht, the asset management (maintenance) domain is just a fraction of the social domain. So yes, we have to do something about it. […]"-(I6Q1L8-12)

As a consequence, the utility of digitisation within the organisation is minimised whereas the digital technology – in this specific example BIM – is already available. This reinforces the statement of van Buuren that mentions culture to be the main bottleneck, not technology.

The key is knowledge development and sharing

Furthermore, the perceived importance of knowledge development and sharing is at par with digitisation. Also with regard to this criterium, complementary interconnections with innovation, digitisation and standardisation can be identified. Hence, with the appropriate strategy, collective development of knowledge can significantly enhance to the overall productivity growth within the civil engineering sector. More specifically, the availability and usability of knowledge in digital technologies – such as developing and using machine learning algorithms – is significantly improved if agreed-upon standards are established and if done correctly, the effectiveness and efficiency of these technologies also increases.

"Dijkhuizen: […] In many places the same things are occurring. You mentioned that within networks these efforts can be exchanged. But what you now see is that many of the same models are being made, the same data is being collected so what it boils down to is that many duplicates are being created which is inefficient. The advantage of new algorithms is that you can easily learn from one another and you will possibly need a lot of resources [information] but it would be advantageous if it all looks the same (adheres to the same format). Same algorithms, same data but also the same contracts. […] *Well we view digitisation and innovation from the machine learning and Artificial intelligence perspective and basically everything with sensors and data. But, we (and our competitors) are perfectly capable of constructing those algorithms but this is only able to contribute given certain standardised components. Standardisation would imply that the same data sources, formats and methods are used. This also incorporates the same asset management methods. The aforementioned, then also has strong ties with knowledge development and sharing implying that it is important that the information is available. […]" – (I5Q1L6-12)*

Additionally, knowledge development and sharing is expected to contribute to the establishment and distribution of guidelines and codes in the civil engineering sector. Thus, overcoming the obstacles presented by the current yet outdated rules and regulations; this will drive institutional innovation leading to more efficient construction processes.

"Molenkamp: In the current situation in question regarding bridges and civil engineering structures, I think that primarily knowledge development and sharing is of importance. […] In all those points we observe that obstacles occur in the existing yet outdated rules and regulation. With that (knowledge sharing and development) you should be able to overcome such obstacles. […]" –(I3Q1L6)

Even though the contributions of knowledge development and sharing are promising, qualities of openness and transparency required for this and are currently not embedded within the sector's culture and requires public actors to take initiative.

"Van Rooijen: […] With regards to knowledge development and knowledge sharing: I think that the collective development of knowledge is very important. Explicitly adhering to principles as openness and transparency when sharing knowledge is a key task of a government. I don't think this is something that will be initiated by the market itself. […]" –(I4Q1L2)

Nevertheless, some cultural change towards a more open and transparent culture can be noticed, especially in initiatives such as the open learning environment circular viaduct. Yet there still is an organisational and financial obstacle holding back the full potential of knowledge development and sharing, one that is rooted in the project-based organisation of the sector.

"van der Vaart: […] I support knowledge development and sharing. And thankfully with the open leeromgeving circular viaduct we see the public and private actors work together in such an environment. But you also notice that contractors are project-based organisations for which it is difficult to allocate a budget to such endeavours (knowledge development and sharing) since they have to earn money with acquiring and completing projects. This makes it difficult in the long-term for both parties (public and private) to keep investing. So is the government always willing to allocate budgets and resources for such things? I think this makes it quite difficult. […]" –(I6Q1L16)

Concepts of resilience and proactivity need to be further developed

Even though resilience is one of the less 'popular' criteria, resilience seems to be an crucial property of the sector to deal with uncertainties. Especially in the aftermath of some crisis. In the specific example provided by van der Vaart, the civil engineering sector was unable to collectively deal the national construction crisis caused by the PFAS compound. Thus, indicating a lack in the sector's resilience and ins such a way also negatively impacting the sector's productivity.

"van der Vaart: Resilience, well quite the open door. But if you look at the current issue of PFAS (a compound that has been at the centre of a national construction crisis in the late 2019), to what extent is the society and contractors resilient enough to deal with such a set-back?

Interviewer: It was quite dramatic…

Van der Vaart: Now we have found a compound and we will most probably discover more compounds. Also the order portfolio [orderportefeuille, the ongoing projects of a contractor] of contractors might give them breathing room for half a year but after that their portfolio empty. We would like to be more resilient, yet it remains difficult." –(I6Q1L18-20)

As such, resilience is primarily associated to the flexibility of humans and organisations to identify and successfully react to new opportunities and challenges. Even while operating within the current institutional infrastructure.

"Molenkamp: […] The current institutions […] are quite rigid. From the moment you are going to operate in the void between those institutions then one could be able to make a leap forward. This is partly incorporated in your work as you could consider it as innovation of work processes and simultaneously it is about the resilience of humans and organisations: i.e. how flexible are you to move within the boundaries that you have or just outside the boundaries such that you can create something new and beautiful together." –(I3Q1L6)

Nevertheless, resilience and proactivity did not received the same amount of attention in relation to the other criteria. One of the identified causes to this result is that resilience was not perceived to be as easily conceptualizable in comparison to more straightforward criteria such as standardisation and digitisation.

"van Rooijen: […] The criterium of resilience is not measured easily so up to what degree can you consider this as a criterium? If I consider the 'open leeromgeving' [an initiative of Rijkswaterstaat to develop a prototype circular viaduct] we chose criteria such as "materials" and "design". Those are criteria that are more easily assessed than resilience. You also observe a certain degree of proactivity in standalone projects. I believe that proactivity is bound to the individuals involved. That is why I think that human capital is an important criterium that has not been mentioned yet. It is something on which success factors and probabilities in projects, facilitating change and innovation are dependent on the drive of individuals within those projects, portfolios or networks." –(I4Q1L2)

Furthermore, van Rooijen suggests proactivity is strongly related to the drive of the involved individuals. In extension to this, Dijkhuizen suggests that stimuli such as reputation mechanisms can increase proactivity as he believes that individuals find it important to be acknowledged.

"Dijkhuizen: Concerning proactivity, I always call this gamification, at least something related to reputation, but we should not underestimate the drive of humans to be acknowledged. There have been many cases where we won contracts where the innovation manager wanted to go public with this. So it is in our nature that we are willing to show that we are doing and developing new and good things. So I think that proactivity is also really important."

Other criteria that influence productivity growth

The frequency with which the 'other' criteria are mentioned are visualised in figure 19. Additional criteria that were frequently mentioned are collaboration and human capital (that is related to proactivity), but also barriers such as individual interest (including competition), and other barriers (in the general sense) that obstruct sector-wide productivity such as the ageing workforce, rules and regulations, culture. However, some of the barriers mentioned were countered with a 'positive' criteria – for example the ageing workforce is countered by industrialisation and automation.

"Mak: what I am still missing is one of the limitations that hamper accomplishing the necessary productivity growth is the available labour capacity in the market – the required yet lacking labour force to realise the assignment. And in order to compensate for those shortfalls you will need to mechanise, automate and industrialise processes. You just mentioned the process innovations but I think that the operational side should be explicitly mentioned. If we indeed want to realise the 'factor 20' acceleration with the least possible costs and the same quality, we will need to industrialise, mechanise and automate certain processes to compensate the shrinking labour force. This is what we are noticing with our welders for example. For that reason we have developed a welding robot." –(I1Q1L13)

"Dijkhuizen: But I think issues such as the ageing of the sector is a problem that might hamper productivity. So I think automation will help us the coming years and I think that it is absolutely necessary."

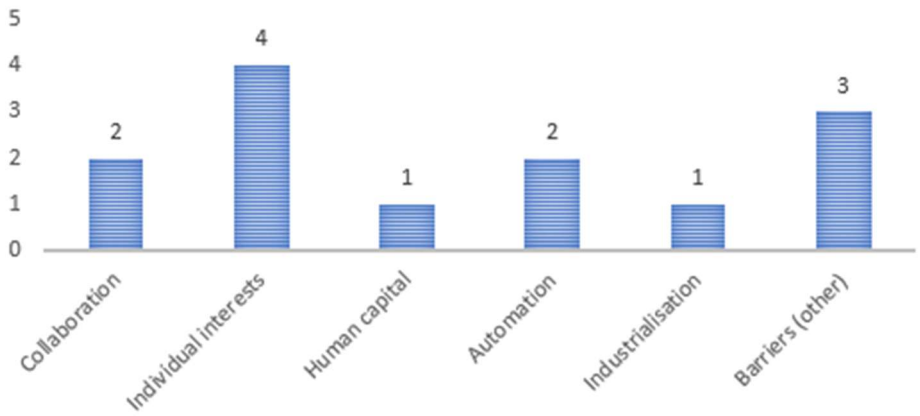


Figure 32: Histogram of other criteria identified from the interviews (source: interview transcriptions Q1, made in excel)

Need for better collaboration

Collaboration is an important aspect for the productivity growth within the civil engineering sector. It aligns well with the other criteria and can be considered to be related to knowledge development and sharing, digitisation and standardisation as collaboration facilitates those criteria. Specifically collaboration should focus on improving the way interactions among actors within the sector are organised/ Preferably to create a sense of community and locality – something that digitisation appears to facilitate (shared situational awareness) – that significantly contributes to the success of a project.

"Mak: I think I am missing the collaboration. What we have been discussing beforehand, the village feeling. You could position this under innovation: we need to change the way we go about with one another. If we approach collaboration in such a way it could be considered as innovation. But if we reason in such a way, we could argue that digitisation is also a form of innovation. […] When looking at a project, these are the key ingredients. You can ask yourself, what is it that determines the success of a project? Inevitably the collaboration (do we have the appropriate professions, competence and capacity) […] both inside and outside the project boundary. With that I take everyone that contributes to the project into consideration. Independent with what organisation they are affiliated." –(I1Q1L9-20)

Similarly, the importance for stimulating local collaboration was also expressed in the case of municipalities. Leveraging local actors whom have a close connection to the city improves their capacity for collective action.

"van der Vaart: I think that for an organisation such as the municipality of Utrecht, that the local collaboration is very important. A sector wide collaboration, not only on project basis but more like a portfolio approach wherein we see a benefit to collaborate with local contractors or other parties – such as knowledge institutes – that have certain connection with the city of Utrecht. Such that we can collectively take action within the chain (of the sector)." –(I6Q1L36)

Taking the abovementioned into consideration, there seems to be a need for an approach that is able to stimulate collaboration in and around the rehabilitation projects such that the capacity for collective action is improved. A village feeling insinuates that actors are comfortable and familiar with one another

in terms of competence, capacity but foremost interests. The concept of locality is desired here, suggesting closeness and fit between the involved actors.

Individual interests in competition pose barriers to innovation and standardisation

Nevertheless, individual interests negatively impact collaboration due to the fixation on short-term results. More specifically, it boils down to the drive of private actors to acquire and execute projects in the short-term while neglecting long-term benefits. As such, it becomes important to incentivise and coordinate on the bases of such long-term benefits and suppress short-term individual interests.

> *"Molenkamp: […] personal interests just to name something. Speed is one of them. The actions taken by an individual (agent e.g. actors on personal, group or organisational level) in a specific context might be faster when working alone instead of together which could be suboptimal but that individual in particular will have a result. […]"*

Additionally, individual interests in competition are related to acquiring exclusivity rights, such as patents that legally protect one's intellectual property. Yet, the existence patents makes it difficult to standardise certain products. Given the expressed importance of standardisation to realise productivity growth, competition with regards to exclusivity will act as a barrier.

> *"van Rooijen: […] Within this chain you are confronted with competition. Then it becomes of interest, from the perspective of competition, to have exclusive rights to produce a certain product. So when you are moving towards standardisation then that will be something that you need to take into consideration. […]" –(I4Q1L2)*

Within the sector, the same principle holds for innovation. If a private actor decides to claim exclusivity on a particular innovation, then it becomes impossible for public actors to implement that innovation in other projects due to the openness constrain imposed by procurement law. As a consequence, this lowers the sector's capacity to become more effective.

> *"van der Vaart: […] how do we implement innovation in a meaningful way? We have to take into account the purchasing of [inkoop; other translation is acquisition] projects such as bridges and quay walls. Some nice developments such as composite materials are completely legally protected with patents by their inventors. So then you become dependent on a single party. A government is not able be dependent on a single party since public procurement requires openness. Thus, this mechanism causes innovation to be held back." –(I6Q1L2)*

The straight-forward solution might be to lift all exclusivity rights such that innovations can diffuse across the sector. However, as the governments mainly outsource knowledge and innovation, the current incentives and culture prevents this from happening even though it is in the best interest of the sector as a whole.

> *"van der Vaart: […] the government stimulates that knowledge and innovations are developed by the market. However, it is not an open source innovation. It is probably an advantage and also a financial advantage for the contractor to protect its innovations. Then it is in the best interest of the contractor. But reasoning from the interest of the sector as a whole this is not the case."*

B6.2 Reflections on the three approaches

All experts indicated that the presented approaches are representative and recognisable. More specifically, all respondents associated the project approach with the current approach in the sector.

> *"van Buuren: The project approach is the way it is today." –(I2Q2L2)*

Furthermore, a significant number of experts suggested that the currently implemented performance-contracts share characteristics with the portfolio approach – for example the longer duration of the contract that gives room for more intensified cooperation and innovation.

> *"Dijkhuizen: What I see with performance contracts which are long term spanning multiple years that it leads to a lot of innovation." –(I5Q3L4)*

> *"van der Vaart: With the portfolio approach I also think about framework contracts. For instance in the municipality of Utrecht the maintenance of roads is in the coming years awarded to a party. You do not necessarily give a whole portfolio but on the basis of certain factors you engage in a longer period of more intensified cooperation in which you can start to think about improvements and such." –(I6Q2L2)*

Additionally, the portfolio approach is more similar to the current project approach as it is an approach consisting of multiple projects that are bundled together and more familiar within the sector.

> *"van Rooijen: What you conceptualise as a portfolio approach is somewhere in between the project and network approach but also resembles characteristics of the traditional approach. This is of course logical since portfolios are multiple projects bundled together so the approach remains the same but there are more projects." –(I4Q3L22)*

On the other hand, the sector is not familiar with network approaches as they are not seen in the civil engineering sector, with the exception of the municipality of Amsterdam. In the case of Amsterdam (one of the regions where the rehabilitation assignment is felt hardest), the three approaches are experienced to be combinable and evolutions of one another. There they went from a project approach to a portfolio approach, and then to a network approach within a year.

> *"Molenkamp: I think that all three approaches are representative and that in practice also combinations of approaches emerge. In time, all three approaches can be traversed simultaneously. The example that I would like to give here is that of Amsterdam where within a year they moved from a project to portfolio and finally are approaching a network approach where within the network approach a portfolio approach is being maintained. So yes, I think that this is a reasonable schematic display of reality." –(I3Q2L2)*

Moreover, in the open learning environment of the circular viaduct, a slightly different path was taken, namely, they started reasoning from a network perspective towards a project perspective.

> *"van Rooijen: Well, it is a division of approaches that is recognisable. If I look at the 'open leeromgeving', participants are sometimes still thinking within the project approach. Whereas we decided to reason from a sort-of network approach and related it to a portfolio approach. Where, as of today three projects are participating. We started as an open learning environment [translation of open leeromgeving] in which multiple actors have participated, so we made a reverse movement. So I do not know if they need to be different per se. They could also be integrated."*

The goal of the open learning environment was to incorporate network-like characteristics in the learning process and designs, but to reflect such qualities in a project-centric world-view compatible with contemporary culture. Noteworthy to mention here, is the integrated perspective to the three approaches.

This is similar to the case of Amsterdam where a network approach essentially evolved from project and portfolio approaches. This possibility suggests that, if desired, a transition from project to network approach is possible by exploiting the portfolio approach as an intermediary step.

> *"van Buuren: You cannot go to a network approach at once so you will need a sort of in between variant. I think that eventually we will end up somewhere in the network approach paradigm." –(I2Q2L2)*

B6.3 Reflections on the respective effect of a specific approach on the criteria

The presented effects are found to be justified and relevant by most experts. However, some expressed the need for more nuance with regards to standardisation and innovation. More specifically, standardisation, according to van der Vaart, in the state-of-the-art also has characteristics of bottom-up initiation.

> *"van der Vaart: the NEN picks up such standardisation efforts that consequently propagate through organisations. I myself have been involved with the development of one or two codes. So in my experience the NEN also has a bottom-up mechanism because market parties are invited to participate in the design of a code even so such parties are then obliged to provide a contribution to keep the committee alive. But, when the code is effectuated then the mechanism becomes rather top-down but formally it begins bottom-up. It could be a trade association or any other stakeholders that contribute to the code. So this complicates standardisation and I have my doubts as it is not exactly top-down." –(I6Q3L2)*

Whereas, according to van Rooijen, standardisation always requires top-down validation. Or in other words, standardisation through consensus by peers is not possible, it requires acknowledgement of an authority for it to be called a standard. Van Rooijen claims that even with regards to the network approach validation is needed by a dominant actor. He states that, among the actors, there is a power distribution consisting of dominant and subdominant actors. According to his perception, this differentiation is essential for the functioning of a network. Furthermore, according to the latter expert, innovation in the project approach should be possible due to available budgets allocated by public actors. Nevertheless, whether innovation actually occurs is debatable.

> *"van Rooijen: […] I do not think standardisation can happen bottom-up. I think this can only be possible if you have a top-down validation. […] It only becomes a standard when top-down it is acknowledged as such." –(I4QL6-8)*

> *"van Rooijen: […] there is a dominant node within the network approach where you would still need the validation of the dominant node. […] A network should be in balance otherwise it is not able to move and be functional. So, a functional harmony should emerge such that projects can operate successfully. This can only work if you differentiate between dominant and subdominant. So if there is no functional harmony there is in my opinion not much you can do. […] I think that within the rehabilitation assignment Rijkswaterstaat and the provinces are dominant. Not even all provinces." –(I4Q3L38,56,58)*

> *"van Rooijen: […] Innovation from the project approach, well I don't know, some projects have a fixed budget allocated for innovations. So then there is a concept of innovation in the project approach. There are contracting authorities that allocate a certain percentage of their budget to innovations. I am wondering whether it can then still be innovation. Innovation is not a department in my opinion. […]" –(I4Q2L20)*

With respect to portfolios, Dijkhuizen suggests that performance contracts lead to a lot of innovation, more so than with bridges that are rehabilitated in separate projects. This is due to the certainty of repetition across multiple bridges which makes it more attractive to invest in innovations. However, he also states that, if these innovations are diffused in a network and on which new innovations are built they may lead to a lot of progression.

> *"Dijkhuizen: What I see with performance contracts which are long term spanning multiple years that it leads to a lot of innovation. If you have innovated in a portfolio, share this within the network whom also innovates and then gives it back again; you will have accomplished a lot of progression. Generally, within a portfolio you have a lot more innovation than when you consider the same bridges separately. Because within a portfolio there is certainty that you are able to implement your development (innovation) over and over again in the other bridges as well." –(I5Q3L4)*

Additionally, some experts suggest that the presented effects should be more nuanced by including other criteria. When including certain barriers, it is expected that the network will score lower, for example, when including the current competitive climate, the network approach would underperform with respect to projects and portfolios.

> *"Heijmans: If you would include competition in the comparison. Then I think the network approach will get a minus score." –(I1Q3L2)*

> *"Molenkamp: […] You can question yourself, when I look at the table and is in line with an earlier comment in the first question, if the network approach is so effective but still is not reality as we speak, then you can state that everyone in the Netherlands is out of their mind: why are we not doing it with one another? […] I would spent time on the contrasting factors since they allow for a more nuanced image." –(I3Q3L4,10)*

A final remark with regards to the effects and assigned factors, when the resolution (of the approach and problem) is increased, then conceptualizing the effects becomes a more complex endeavour. This can be interpreted as the effect the criteria have on one another, but also the more detailed technical and institutional processes that characterise those approaches.

> *"Molenkamp: I think that given the choice of the model and the information density of the model that it is a good representation. If you take each cell and expand it in more detail then you would get more differentiated and nuanced answers but on headlines this seems reasonable.*
>
> *Interviewer: So the completeness on this level of resolution is reasonable while acknowledging the depth of each factor?*
>
> *Molenkamp: Exactly, then it could just be the case that you stumble upon circular reasoning which you might want to look at." –(I3Q3L2-4)*

B6.4 Reflections on the most feasible approach

From the previous reflections, some educated guess can be with regards to the most feasible approach. Although productivity growth does seem to be necessary in the rehabilitation assignment, there are still barriers that hold the sector in a headlock with regards to adopting new approaches. As a consequence thereof, most experts appointed the project approach to be the current most feasible approach.

> *"van Buuren: […] If I look at the history, I think the project approach is currently most feasible. […]" –(I2Q4L2)*

"Dijkuizen: I think that we are often going to fall back to projects. Because many of our currently in place systems revolve around a project to project philosophy. For instance projects are still individually procured. […]" –(I5Q4L2)

"van der Vaart: Which approach is the most feasible, when I look at my profession – the GWW in the civil engineering – the project approach since it is the currently most compact […]" –(I6Q4L2)

This is mainly because, even the portfolio approach, which said to be closest to the project approach, is still difficult to implement with the current boundaries and culture of the sector. These barriers are perceived to occur both on side of the public and private actors.

"Mak: I think within the current boundaries and culture of the sector including the government, that, even a portfolio approach is not feasible yet. […]

Heijmans: I also think that this is the case." –(I1Q4L2-3)

"Dijkhuizen: […] A portfolio approach is getting there, with some struggles of course but I think it is a good system. […]" –(I5Q4L2)

Although, some address its difficulties, van Rooijen mentioned the portfolio approach to be the most feasible because of its conceptual overlap with the project approach and thus being a logical next step given that the civil engineering sector is not directly ready for a network approach. This is complemented, by Rijkswatertaat's current conceptual experiments of portfolios, and the already existing long-term contracts that are widely applied throughout the civil engineering sector.

"van Rooijen: The portfolio approach. […] Because the network approach is not yet there. […] If you want to put things into motion it should not be too distant from what is familiar. Thus it is a logical step to move from a project to a portfolio approach. […]" –(I4Q4L2-6)

In a similar fashion, van Buuren suggests that the portfolio approach can be implemented. However, as he has already mentioned, the bottleneck is culture and is not convinced that a portfolio approach is going to be able to cause the sector to change culturally.

"van Buuren: They say that because the contractors convincingly say: "give us 10 bridges" and we will fix it. But take my word, they will not. Perhaps the portfolio approach can be implemented, but the contractor is not going to learn and change within those 10 bridges. Why should they learn when these 10 bridges are bundled together in contrast to when those 10 bridges are taken separately. It is a matter of culture. There is a need for different people with different qualities. I do not believe that a contractor all of a sudden is going to learn when he gets 10 bridges at once." –(I2Q4L10)

An expressed longing for change towards a network approach

Even though all of the experts mention that the network approach is currently difficult to implement or not feasible with the contemporary culture, they all expressed the desire and need for such an approach within the sector especially given the complexity of the rehabilitation assignment. Van Rooijen even goes beyond the civil engineering sector suggesting a network approach that transcends other infrastructure related sectors to include other relevant infrastructures such as the water irrigation, telecommunications and energy infrastructures.

"Dijkhuizen: I think that the network approach is the only one that is able to solve the problems surrounding the rehabilitation assignment. Especially due to its size, especially in bridges and

civil engineering structures. […] I see it increasingly emerging within the market and that it is moving toward that direction." –(I5Q4L2-8)

van Rooijen: Given the current time and contemporary organisations, yes. But to really be able to realise the rehabilitation assignment we need a system-innovation. […] That the connectedness of the network approach, transcends the (civil engineering) sector. –(I4Q4L34,38)

As aforementioned, the three approaches are considered to be evolutions of one another and can thus be integrated. Molenkamp, a proponent of the network approach, relates the network approach to the approach proposed by the 'de bouwagenda'. She positions this approach in between the portfolio and network approaches. More specifically, 'de bouwagenda' suggests to create portfolios on a network level such that similar initiatives can be whilst simultaneously engaging in long-term contracts with one another to ensure continuity.

"Molenkamp: I really believe the network approach. And this approach, like you have indicated, will have manifestations of 'swarms' with specific portfolios. I believe that this is in line with what we have identified to be important in 'de bouwagenda': make baskets (a portfolio approach) but do so on a network level. In other words, look where specific approaches (e.g. project processes) are applicable and connect those with one another and engage in contracts spanning multiple years. The approach posited in 'de bouwagenda' is in between 2 (portfolio) and 3 (network) – has elements of approaches 2 and 3 – and I think that this holds the future." –(I3Q4L2)

As aforementioned, going from a project to network approach requires a transition with an intermediary step, in section 5.1.2 it appeared that portfolios can function as an intermediary stepping stone. However, according to van der Vaart and in line what has been previously mentioned, in order to facilitate this transition, barriers would need to be overcome with regards to the organisation of the sector and rules and regulation – for instance ensuring networks are enabled within the procurement law.

"van der Vaart: But what I am dreaming of is that the network approach takes off. However, in order for that to happen certain barriers must be overcome since we have to start organising ourselves differently, we have to adapt the rules and regulations etc. If you look at the public procurement law, it is oriented around the fairness of competition among market parties to earn projects. But as I might have already told you earlier this interview we should start incorporating more aspects. For instance how can we engage and stimulate civil participation, how can we stimulate regional efforts such as the use of regional materials but you will need a network in which the governments are in constant consultation with the market and specifically the parties with which you desire to connect." –(I6Q4L2)

Especially with regards to the sector's organisation, changing the conditions wherein knowledge sharing becomes easier is expressed to be needed. As identified in previous data extracts, these conditions are organisational, cultural and institutional.

"Mak: For the network approach however, the right boundary conditions need to be facilitated such that it becomes easier to share knowledge. We can see the initiative of de bouwcampus taking shape, but the way that it is currently organised is not sustainable and I do not expect this to change within the forthcoming 5 years." –(I1Q4L2)

Fortunately, however, knowledge sharing across geographical and organisational boundaries can be facilitated through leveraging digitisation in the form of online networks – such as platforms and virtual organisations.

> *"Dijkhuizen: Yet, with networks I see a local network, such as the provinces of Groningen and Zee-Land as you mentioned in your examples [the example mentioned two physically separated provinces with common issues, where a network could stimulate the awareness of their shared issues and improve their knowledgeability] that there should also be an online network supporting this. (I5Q2L4) […] also for that network to be supported digitally. Like what you see in stack overflow, GitHUB etc. With an online network sharing becomes easier." (I5Q2L4,6)*

Apparently, the ability to share knowledge is paramount for the success of the rehabilitation assignment. Complementary to this, the network approach is perceived to be a good enabler of knowledge sharing as it is characterised to facilitate interorganisational connectivity.

Appendix C: Coherent Institutional and Technological Design

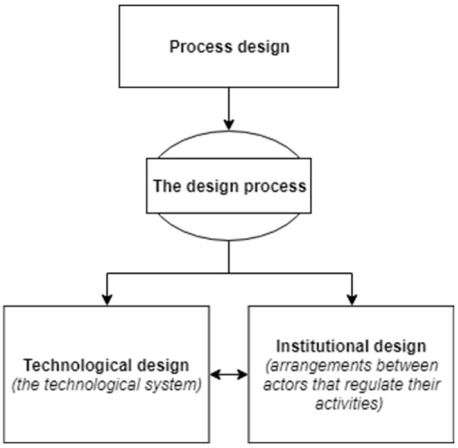


Figure 33: Processes and designs that lead to a comprehensive system consisting of technological and institutional design perspectives (Koppenjan & Groenewege, 2005)

Process design

Process design according to "Process management"; it includes the whole programme lifecycle from conception to retirement. It looks at the programme from a multi-agent perspective where interests are aligned and concessions are made such that a common goal can be achieved. This is often a multi-stage process consisting of multiple negotiation rounds through which the process progresses.

Design process

At one part of the within the process design, the programme concept must be expanded into a complete and functional programme design. Such a design combines institutional and technical considerations of the programme. Within this thesis the aim is to provide a design process in which a functional 'sociotechnical' description of the programme can be provided. The functional description is based on the essential functions (Critical functions of the programme).

Consequently, this would require a design process that takes into account the established functions and requirements of the programme from both a technological and institutional perspective.

Cohesive technological and institutional design

A functional 'sociotechnical' description requires a design is essential that incorporates the interconnected technological and institutional dimensions. In this attempt, it is important to ensure that there is a certain degree of '*coherence'* between the technological and institutional coordination of the system's essential functions. The author stresses that *"coherence would be realised if the technological and institutional coordination of the essential functions should is based on similar coordination*

mechanisms with a comparable scope of control" since deviations would result in system performance that does meet the requirements and expectations (Kunneke, 2009).

From the abovementioned figure (figure 33) the interrelation between the technological design and the institutional design is visualised by the horizontal bi-directional arrow between the two boxes 'technological design' and 'institutional design'.

The technological design constitutes the morphology of the technological system – the system architecture, its components, relations between the components and the processes that the system facilitates – according to requirements established in the design process. In the context of this thesis, the technological system hosts the technical processes of the rehabilitation programme such as information exchange through distributed ICT relevant for project processes.

The institutional design on the other hand constitutes the arrangements that regulates the relations between the actors that participate in the rehabilitation programme delivery such that the performance of the system can be guaranteed; institutions facilitate the coordination and reciprocal (balance between contribution and exploitation) behaviour of participating actors in the programme (Koppenjan & Groenewege, 2005).

Supplementary materials

- Interview transcripts and codebook with extracts