

# THE DOCUMENTATION OF DESIGN DECISIONS IN CIVIL ENGINEERING PROJECTS

**An application in road infrastructure development**

**TARA KINNEGING**

**University of Twente & Witteveen+Bos**

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## AN APPLICATION IN ROAD INFRASTRUCTURE DEVELOPMENT

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#### Conducted by:

A.L.T. (Tara) Kinneging BSc  
s1318438  
a.l.t.kinneging@student.utwente.nl

#### Commissioned by:

ir. T. (Tim) van Dijck  
System Integration  
PMC Smart Infra Systems  
Witteveen+Bos

dr.ir. R.S. (Robin) de Graaf  
Construction Management and Engineering  
Faculty of Engineering Technology  
University of Twente

S. (Sander) Siebelink MSc, PDEng  
Construction Management and Engineering  
Faculty of Engineering Technology  
University of Twente

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# PREFACE

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This paper is written to present the research that was conducted as final part of the master Civil Engineering & Management at the University of Twente, the Netherlands. This research was commissioned by Witteveen+Bos and focuses on the documentation of design decisions in civil engineering projects, applied in road infrastructure development.

This master thesis project marks the end of my student life, and I could not have wished for a better completion. I was given numerous opportunities to expand my knowledge and as a result, I have learned a great deal. This would not have been possible without the help of others.

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# The documentation of design decisions in civil engineering projects

## An application in road infrastructure development

A.L.T. Kinneging<sup>1,2</sup>, R.S. de Graaf<sup>1</sup>, T. van Dijck<sup>2</sup>, S. Siebelink<sup>1</sup>

<sup>1</sup> University of Twente, Enschede, the Netherlands

<sup>2</sup> Witteveen+Bos, Deventer, the Netherlands

### ABSTRACT

Documentation of design decisions contributes to the traceability of significant decisions that shape a project's development process. It helps to deal with changes in the project and prevents the recurrence of old discussions. Yet little attention is given to the documentation of design decisions in SE and civil engineering literature. In this study, a theoretical framework for the key elements of this documentation process was developed. Four road infrastructure SE projects were studied and compared to this framework by means of pattern matching. This method compares theoretical and empirical patterns and determines whether they match or do not match. This analysis helped to identify if documentation of design decisions in current practices is in keeping with theory or not. The findings of the project studies demonstrate that the accessibility of documentation for all involved project parties and distribution of documentation tasks are in line with literature. However, the explicit documentation of design decisions and their rationale is not as extended as is recommended in theory. In literature, also the documentation of interrelations and context of decisions is described, but this is hardly performed in practice. Findings show that in current practices, neither immediate documentation nor periodical monitoring is applied, as recommended in literature. This research also provides a strategy for the documentation of design decisions, which aims to improve the key elements of this documentation process in civil engineering projects. This strategy was developed for a specific engineering consulting firm and it was validated by experts of this firm, specialized in other disciplines of the civil engineering sector than road infrastructure.

**Keywords:** systems engineering, design decision, civil engineering, documentation strategy

### 1. INTRODUCTION

The documentation of design decisions is of great importance as it improves the ability to trace decisions and thus provides more insight in what decisions have been decisive in the project development and why. In the Dutch civil engineering industry, Systems Engineering (SE), which facilitates structured documentation in the design of complex systems, is applied in the majority of projects (INCOSE, 2015; Rijkswaterstaat & ProRail, 2013). However, problems still occur in many projects due to incomplete or incorrect documentation (de Graaf et al., 2017; van den Houdt & Vrancken, 2013; van der Meer et al., 2015).

In the civil engineering sector, projects often have a long duration and are dynamic in nature (van den Houdt & Vrancken, 2013). A project consists of multiple phases that have to be completed during the design of new, or modification of existing infrastructure. For Dutch

governmental road infrastructure, project organizations are obliged to follow the phases as described in the MIRT phasing and Transport Infrastructure Planning Act<sup>1</sup> (Ministerie van Infrastructuur en Milieu, 2016; Tracéwet, 2017). The execution of these different phases requires the involvement of different specialized parties. Information is transferred between different involved parties, but also from one phase to another. Documentation is thus of great importance as it is the main means to transfer this information from party to party and phase to phase. However, problems concerning the documentation of design decisions are identified at these transitions (van den Houdt & Vrancken, 2013). A

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<sup>1</sup> MIRT is the multiple year program for infrastructure-, spatial planning- and transport projects of the Dutch government, provinces and municipalities. The Transport Infrastructure Planning Act describes the obligatory procedure for the development of road infrastructure.



clear baseline for the project is not always established as the documentation provided in these transitions is often incomplete or missing in many projects (Farnham & Aslaksen, 2009). Subsequently, the quality of input-documentation appears to be a problem even for a phase itself. Project disciplines do not receive the information they require, or the documentation is provided too late (Luo et al., 2017). Moreover, design decisions are not always communicated with those involved within the project organization (Elliot, 2012; van den Houdt & Vrancken, 2013). As they are dependent on the documented information of others, as a result, different teams cannot continue their work activities or they have to make assumptions which may turn out to be wrong (van der Meer et al., 2015).

Although SE is meant to improve transparency and traceability, the use of SE does not ensure a conclusive procedure for the documentation of design decisions (van den Houdt & Vrancken, 2013; van der Meer et al., 2015). Therefore, approaches and formats differ per organization or team, which makes tracing information a tedious and time-consuming task (Chachere & Haymaker, 2011; Farnham & Aslaksen, 2009). A high level of effort is also required for managing and controlling changes in project scope and requirements (de Graaf et al., 2017). It is hard for stakeholders or members of the project organization to determine which design decisions have been made earlier in the process and how these affect or are affected by the changed parameters (Luo et al., 2017). Moreover, a lack of procedures also results in ambiguities about people's responsibilities for both making and documenting design decisions (van der Meer et al., 2015). This results in miscommunication between the different involved parties, but also between individuals of the same team. At last, discussions in projects are repeated multiple times as no documentation can be provided based on which the discussion could be closed (van den Houdt & Vrancken, 2013).

As application of the SE methodology seems not able to prevent or solve these problems, the development of an additional strategy for the documentation of design decisions in civil engineering projects is considered relevant by multiple organizations. These organizations are involved in civil engineering projects as clients, engineering consultants and contractors.

The objective of this study is to investigate current practices and provide a strategy for the documentation of design decisions in civil engineering projects. A literature research has been performed, current practices have been studied in four projects and a concept strategy has been developed and validated. The findings of this study can help to determine which documentation is required, and how to deal with the process of documentation to improve the traceability of design decisions.

In this study, the research question is: what are the current practices concerning the documentation of design decisions in the context of Systems Engineering, and what should a strategy for improving this documentation process comprise, that could be implemented in an engineering consulting firm?

Chapter 2 presents the theoretical framework that has been developed based on previous research on design decisions, SE, documentation and information management. Chapter 3 presents the methodology used to achieve the research objective. Chapter 4 focuses on the analysis and explanation of the findings of the case studies and Chapter 5 shows the development of the concept strategy. Chapter 6 presents the results of the validation of the concept strategy. Finally, Chapter 7 compares this study to existing literature, Chapter 8 presents the limitations and Chapter 9 the conclusion of this research.

## **2. THEORETICAL BACKGROUND**

To establish a theoretical framework, literature considering the documentation of design decisions in the civil engineering industry is reviewed. The problems with documentation in this industry have occurred over a long period of time. However, current research in the civil engineering sector has not led to a solution or new insights on this subject. Therefore, literature of other industries was analysed to generate new input for the issues concerning the documentation of design decisions. First, it was analysed why the documentation of design decisions is required. In literature, what-, who-, when-, where- and how aspects of documentation could be distinguished. This means that the specifics and form of documentation were reviewed, followed by suggestions for assigning documentation responsibilities. Thereafter, the moment and location of documentation were analysed. Additionally, the perspective of literature on implementing a strategy for the documentation of design decisions in the civil engineering industry was analysed.

### **Literature research**

The documentation of design decisions is required to provide both the project organization and different stakeholders with a reference throughout the project (Chachere & Haymaker, 2011). This documentation allows clients, project members and stakeholders to keep track of project changes, but also ensures a good traceability (de Graaf et al., 2016; van den Houdt & Vrancken, 2013). By doing so, knowledge and practices from previous phases could be reused and reoccurring discussions can be prevented (Anumba et al., 2008; de Graaf et al., 2017). This increased efficiency enables a

timely completion of the different project tasks (Pirzadeh & Lingard, 2017). At last, documentation of design decisions could also be beneficial for communication within the project organization as well as it allowing an understandable representation of the design for different stakeholders (Luo et al., 2017).

#### *What*

Literature addresses the specifics of what should be documented concerning design decisions. First, the design decision itself should be included explicitly in documentation (Capilla et al., 2007; Deng et al., 2007; Küster, 2013; Zimmermann et al., 2009). Second, not only a design decision itself but also the rationale behind the decision should be documented (Chachere & Haymaker, 2011; Jansen et al., 2007; van der Meer et al., 2015). The rationale comprises the justification and process that has led to a design decision (Bhat et al., 2017; van der Ven et al., 2006). This rationale is required to determine why a decision has been made, even after a long period of time or if the decision-maker has left the project (Zdun & Capilla, 2013). Third, it is suggested to additionally document the dependencies and interrelations between design decisions (Borches Juzgado, 2010; Pahl et al., 2007). This will provide project members with more insight in the cohesion of the entire system (MacCalman et al., 2015). Fourth, to further extend this system overview, Babar & Gorton (2007) and de Lange et al. (2014) propose to also document a decision's context. The design objects and systems that are affected by a design decision are thus included explicitly in the documentation. The context will provide clarity on different project teams' involvement for a decision, guiding the communication and reflection between them (Hesse et al., 2016).

#### *Who*

A documentation strategy is not complete without assigning responsibilities for both documentation and monitoring tasks (Chachere & Haymaker, 2011). To ensure a continuous and structured documentation of design decisions, the responsibility for this should be given to a specific person (Pirzadeh & Lingard, 2017; van den Houdt & Vrancken, 2013). Defining clear responsibilities prevents discussion on who is responsible for performing specific documentation tasks. This clarity will also improve the communication about design decisions as it is clear for project members who should be contacted concerning a specific decision (Dogan et al., 2011). Furthermore, the responsibility for monitoring and checking the documentation should also be assigned clearly (Farnham & Aslaksen, 2009). Only project members responsible for documenting a specific decision are given rights to do so, similar for the rights

to check and approve the documentation which should only be given to those who have these responsibilities (Tang et al., 2004; Weinreich & Buchgeher, 2010).

#### *When*

To ensure sufficient documentation of design decisions, agreements on the moment of documentation should be made. It is stressed in literature that design decisions should be documented continuously during the project, preferably immediately after making decisions (Anumba et al., 2008; Galliers & Leidner, 2014; van Heesch et al., 2014). As Lee & Kruchten (2008), Weinreich et al. (2015), Tyree & Akerman (2005) and Babar et al. (2006) point out, immediate documentation is required to prevent the loss of information and knowledge. In addition, this documentation should then be evaluated and reviewed periodically (Deng et al., 2007). The periodical review will ensure that documentation tasks are executed, and additionally the quality is monitored (Noordin et al., 2012). Farnham & Aslaksen (2009) also suggest to review previous documentation at the start of a new project phase to provide the project members with a clear baseline. This baseline provides insight in what documentation is present and what information still needs to be retrieved.

#### *Where*

Literature states additional requirements for the documentation conditions concerning the location of documentation. As many parties are involved in civil engineering projects, the transfer of information should be considered (Elliot, 2012). Easily sharing documentation is considered very important in a project organization (Maier & Hädrich, 2005; van den Houdt & Vrancken, 2013). In order to safeguard sufficient traceability and smooth transition of documentation across phases and people, good accessibility of the documentation is essential (Elliot, 2012; Mena et al., 2010; Noordin et al., 2012). Therefore, involved project parties should be provided with good access to the latest documentation at all times (Jansen et al., 2008; van der Meer et al., 2015). Often a web interface or software application is recommended as storage and retrieval location for documentation, sometimes complemented by a repository or database (Anumba et al., 2008). Within such an environment, the use of a pre-defined template or query could present structured and uniform documentation, but it also supports the user in documenting decisions (Farnham & Aslaksen, 2009; Mena et al., 2010; Noordin et al., 2012).

#### *How*

The first four aspects of documentation describe the content and conditions, but theory also addresses the

format in which the documentation could be captured. Anumba et al. (2008), Kruchten (2004) and Mena et al. (2010) suggest documenting design decisions and their dependencies in the form of an ontology. This is a network in which all properties and relations of design decisions are documented and visualized in a web (de Lange et al., 2014; Ming et al., 2016; Oude Luttikhuis et al., 2015). Another possibility to visualize the decisions is to connect them to their context. This could be visualized by placing design decisions in conceptual drawings or models (Brussel & Bonnema, 2015; van der Meer et al., 2015). By doing so, a decision is shown directly connected to the objects in the design that it affects (Tang et al., 2004).

#### *Implementing a strategy for the documentation of design decisions*

Existing literature in the civil engineering industry points out that difficulties might be encountered when implementing a strategy for the documentation of design decisions. Documentation requires time and effort of the project members, while benefits often cannot be perceived immediately (Farnham & Aslaksen, 2009; van den Houdt & Vrancken, 2013; van der Meer et al., 2015). Furthermore, a new approach might require training for the project members, however proper guidance is currently often not guaranteed (Mena et al., 2010; van

den Houdt & Vrancken, 2013). Additional difficulties occur because of the project-oriented, short-term and task-focused work culture of the civil engineering sector (Noordin et al., 2012; van der Meer et al., 2015). The level of collaboration is generally low, while the number of involved parties is high (Farnham & Aslaksen, 2009). On top of that, van der Meer et al. (2015) add that the documentation provided by the client at the start of the project is often uncertain and incomplete.

#### *General overview*

This literature research combines theory of the civil engineering and other sectors. Therefore, it provides new input which is required to solve long-existing problems concerning the documentation of design decisions in the civil engineering industry. First of all, it is important not only to document design decisions but also their rationale, interrelations and context. This will provide a justification of why a decision has been made, but also shows the decision in relation to other decisions and its context. Because of this, project members will have more insight in the cohesion of the entire system. The responsibilities for both documenting and monitoring this documentation should be given to a specific person, so that all design elements are accounted for. Uniform documentation should be ensured by using a documentation environment in

**Table 1:** Theoretical framework.

Framework	Theoretical patterns	Sources
<b>What</b>	There should be documentation of design decisions and their interrelations, context and the rationale behind decisions	(Babar & Gorton, 2007; Borchers Juzgado, 2010; Capilla et al., 2007; Chachere & Haymaker, 2011; de Lange et al., 2014; Deng et al., 2007; Jansen et al., 2007; Küster, 2013; Pahl et al., 2007; van der Meer et al., 2015; Zimmermann et al., 2009)
<b>Who</b>	There should be clear responsibilities assigned for the documentation	(Chachere & Haymaker, 2011; Farnham & Aslaksen, 2009; Pirzadeh & Lingard, 2017; van den Houdt & Vrancken, 2013)
	There should be clear responsibilities assigned for monitoring the documentation	(Farnham & Aslaksen, 2009)
<b>When</b>	There should be immediate documentation of design decisions, rationale, interrelations and context which should be ensured by periodical monitoring	(Anumba et al., 2008; Babar et al., 2006; Galliers & Leidner, 2014; Lee & Kruchten, 2008; Noordin et al., 2012; Tyree & Akerman, 2005; van Heesch et al., 2014; Weinreich et al., 2015)
	There should be an assessment of all available documentation performed at the start of a new project phase	(Farnham & Aslaksen, 2009)
<b>Where</b>	There should be a documentation environment in which the user should document in a pre-defined template	(Anumba et al., 2008; Elliot, 2012; Farnham & Aslaksen, 2009; Jansen et al., 2008; Mena et al., 2010; Noordin et al., 2012; van der Meer et al., 2015)
	There should be good accessibility of the documentation for all involved project parties	(Elliot, 2012; Farnham & Aslaksen, 2009; Mena et al., 2010; Noordin et al., 2012)
<b>How</b>	There should be a visualization of the design decisions and interrelations in their context	(Anumba et al., 2008; Brussel & Bonnema, 2015; Kruchten, 2004; Mena et al., 2010; Tang et al., 2004; van der Meer et al., 2015)

which the user can document in a pre-defined template. Civil engineering projects have many involved project parties, thus good accessibility to documentation for all parties is very important. To ensure continuous and complete documentation, design decisions should be documented immediately and this should be monitored by periodical reviews. At the start of each project phase, an assessment of previous documentation should be done to provide a baseline of all available information.

### Theoretical framework

By means of this literature study, a theoretical framework has been developed that was used as a reference for both data collection and analysis. The theoretical framework is summarized in Table 1. As literature did not offer one conclusive framework for the documentation of design decisions, the framework has been developed with separate elements from different sectors. As coherence was not present in literature, case study research should be used to determine if cohesion between the elements of the theoretical framework could be found in practice. The relevance and existence of these elements in current practices should also be determined in the case studies. At last, the case study research should provide a better understanding of the different elements of the theoretical framework.

## 3. METHOD

This study has followed a research design developed by means of the proposed approach of Verschuren & Doorewaard (2007). A theoretical framework has been established by performing a literature research. To be able to develop a strategy for the documentation of design decisions, this framework has been compared to current practices. In accordance with the theoretical framework, these practices focus on the documentation on project and not on organizational level. To establish a clear description of current practices in which the contextual conditions play an important role, case study research was used (Miles et al., 2013; Yin, 1994). This type of research strategy has been chosen considering the three conditions for using a case study. First, the research question is of exploratory nature as the goal is to investigate current practices and to develop propositions in the form of a strategy. Furthermore, the studied projects are contemporary and the researchers have no control over the events (Yin, 1994).

This study on the documentation of design decisions has been performed in four civil engineering projects, focused on road infrastructure. Data were collected in these case studies by means of interviews and document analysis. To ensure data triangulation, both these sources were used for cross verification

of the collected data. The case studies have been confronted with the theoretical framework by means of pattern matching (Hak & Dul, 2009). Similarities and differences between theory and current practices have been identified based on this confrontation. Pattern matching was used in this research as it is recommended as strategy for qualitative analysis for case studies, as it will provide critical understanding of the subject (Cao et al., 2004; Yin, 1994). Although it is not a common approach used in developing a strategy, this in-depth understanding helped to define the improvements that are necessary in current practices. Based on these findings, recommendations in the form of a concept strategy are proposed. In this strategy, different elements concerning the documentation process are integrated. Also the manner in which those elements should be applied in practice is discussed. The concept strategy for the documentation of design decisions has been validated in another set of interviews. To validate if the strategy also applies to other disciplines than road infrastructure, the participants of these interviews work in other specializations of the civil engineering industry than those who participated in the case studies.

### Case studies

#### Projects

Four SE projects in the Netherlands were studied, in which a specific engineering consulting firm is involved. In all projects, Rijkswaterstaat (RWS)<sup>2</sup> functioned as the client and SE was thus required to use as RWS prescribes SE in all its engineering projects (Rijkswaterstaat, 2017). The projects all focus on road infrastructure, more specifically national highways. The projects have been selected following the principle of *ceteris paribus*, in which multiple variables affecting a dependent variable are remained constant as much as possible. The industry, client, use of SE and project objectives and sizes are isolated variables in these case studies. The engineering consulting firm has been involved in the projects in different project phases, based on the Dutch Transport Infrastructure Planning Act (Tracéwet, 2017). Therefore, these four cases together provide an extensive perspective on the current practices of the documentation of design decisions in different stages of development in road infrastructure. The projects are as follows:

- Project A: extension of a station and widening of a highway, established by building two tunnels for the road. Studied in the development of the design route decision, route decision, contract

<sup>2</sup> Rijkswaterstaat is the executive body of the Dutch Ministry of Infrastructure and Water Management, and is responsible for water management and the construction and maintenance of public works, including waterways and roads.



development and guidance of the contractor after procurement;

- Project B: widening of a highway and separation of traffic flows. Studied in the contract development;
- Project C: widening of a highway, construction of a switch lane and development of a sunken road construction. Studied in the development of the route decision and contract development;
- Project D: widening of a highway, with the ambition to develop a smart and sustainable road through extensive innovation. Studied in the development of the design route decision.

Each project is developed by different parties at different stages, with a continuous involvement of the client. This research focuses on the involved project members of both an engineering consulting firm and client. Some of these people have been involved in the projects for the entire period of development, others have only contributed to part of the products.

#### *Data collection*

During the case studies, current practices concerning the documentation of design decisions were compared against the theoretical framework that is described in Chapter 2. To collect these data, interviews were conducted amongst team members of four projects, supported by a documentation analysis. The theoretical framework was used as outline for the interview format, so that descriptive data on current practices were gathered for identical elements. These elements describe the what, who, when, where and how characteristics concerning the documentation of design decisions in the case studies.

All participants were interviewed following a structured outline, but with addition of some probing questions if more information was required. Examples of the questions used are “was there a standardized procedure for the documentation of design decisions?” and “what are the major limitations of the current method for the documentation of design decisions?”. The interviews were conducted in a one-on-one setting of participant and researcher and had a duration of one hour. Data have been collected from in total 29 participants; six for project A, six for project B, eight for project C and nine for project D. These participants have been selected for interviews based on their roles and responsibilities. Technical managers of both the client and engineering consulting firm were interviewed for all projects. Furthermore, both people focusing on SE activities and those responsible for the design products have been interviewed. Several designers, technical advisors and design discipline leaders of both client and engineering consulting firm completed the participants.

#### *Data analysis*

The qualitative, descriptive data of the case studies consist of a documentation analysis and interview transcripts. Empirical patterns were formulated for each of the previously defined elements (Miles et al., 2013). This condensed set of data was confronted with the theoretical framework by means of pattern matching. This method compares theoretical and empirical patterns and determines whether they match or do not match (Campbell, 1975; Hak & Dul, 2009). The theoretical framework serves as the ‘expected pattern’, the collected set of data is the ‘observed pattern’. The theoretical pattern thus describes how the documentation of design decisions should be done, while the observed pattern provides insight in how it is done in practice.

The confrontation either results in matches, partly matches or mismatches between the expected and observed patterns. These matches are assigned values on a three-point scale, - indicating that the patterns do not match entirely, o indicating a slight overlap and + indicating a complete match. For each of the elements of the framework, the matches and mismatches were evaluated by means of an explanation which provides an interpretation of the data. A match does not automatically indicate that this pattern should be used in the concept strategy, as the pattern might not have had any significant influence on the case project. If patterns did not match, evaluation was done to determine if this difference in patterns has a significant effect on the documentation of design decisions.

The pattern matching analysis has been performed cross-case to compare the different projects and their confrontations with the theoretical framework (Yin, 1994). The conclusions of these comparisons have resulted in a concept strategy for the documentation of design decisions developed by the researcher.

#### **Validation of the concept strategy**

##### *Participants*

The concept strategy was validated by means of interviews, which were conducted among five participants of the same engineering consulting firm as studied in the case studies. The interviewees have been selected based on their responsibilities and fields of expertise. They are not part of one project team. Although the concept strategy is used by all project members, designers will be those responsible for documenting most design decisions. Therefore, four interviewees have design responsibilities in the projects they participate in and one participant often fulfils the role of information manager. The validation should indicate if the concept strategy is applicable for the entire civil engineering industry. Therefore, the expertise

of the participants is not restricted to road infrastructure, but also comprises movable bridges, flood defences, steel constructions and coastal- and river hydraulic engineering. The participants of the validation interviews did not participate in the first round of data collection, so that input and validation is strictly separated.

#### *Data collection and analysis for validation of the concept strategy*

The validation of the concept strategy is the second moment of data collection. These data are required to determine if the concept strategy meets the needs and expectations of the intended users. The data collection was, again, established by means of interviews among the participants. These interviews focused on both the principles and the practical aspect of the concept strategy. In the first part, the participants were asked about their opinion on the concept strategy. In the second part, the participants were presented with a prototype of the practical implementation of the concept strategy. Afterwards, they were asked about their perspective on the prototype.

Data of the interviews were analysed to be able to validate the concept strategy. Based on this analysis, conclusions and recommendations for future research are described.

## 4. RESULTS: CASE STUDIES

This section summarizes the background of the four case study projects from which the empirical patterns are derived. These patterns resemble the elements as

used for the theoretical patterns. Analysis of the results explains the differences and resemblances between theory and practice.

### Case study results

Pattern matching was used to confront the theoretical framework and current practices (Hak & Dul, 2009). Table 2 shows the summarized results of the pattern match between theoretical and empirical patterns for all projects. The confrontation was scored per element and is indicated by a three-point scale (-/o/+). By adding up the scores of all projects, the elements were ranked from most to least in correspondence with literature. The explanations of the initial scores were used to determine the ranking if the combined score was equal for multiple patterns. The extensive pattern matches for each separate project can be found in Appendix I, Tables A.1, A.2, A.3 and A.4.

These case study results are analysed and explained in the next section. As this research aims to develop a strategy for the documentation of design decisions, it will focus on the general findings of current practices. Therefore, the individual case study results were used to develop a general perspective of the current situation at the engineering consulting firm.

### Analysing the results

#### *What*

The pattern match indicates that the documentation of design decisions, their interrelations, context and the rationale behind decisions was not covered completely in any of the projects. The case study results provide more insight in the differences in documentation of the specific

**Table 2:** Summarized results of the pattern match for all projects.

		Project A	Project B	Project C	Project D	Ranking
<b>What</b>	There should be documentation of design decisions and their interrelations, context and the rationale behind decisions	o	-	o	o	5
<b>Who</b>	There should be clear responsibilities assigned for the documentation	+	-	o	+	3
	There should be clear responsibilities assigned for monitoring the documentation	+	-	+	+	2
<b>When</b>	There should be immediate documentation of design decisions, rationale, interrelations and context which should be ensured by periodical monitoring	-	-	o	o	8
	There should be an assessment of all available documentation performed at the start of a new project phase	-	o	-	+	7
<b>Where</b>	There should be a documentation environment in which the user should document in a pre-defined template	o	-	+	+	4
	There should be good accessibility of the documentation for all involved project parties	+	-	+	+	1
<b>How</b>	There should be a visualization of the design decisions and interrelations in their context	-	o	o	o	6

- patterns do not match, o patterns match partly and + patterns match. The ranking indicates the correspondence of the pattern with literature, from most (1) to least (8).

aspects. Project teams document design decisions and rationale, however embedded in large documents as integral design notes. Clients often request only these specific documents, so because of time pressure and short-term deadlines no additional effort is spent on documenting more explicitly. In projects C and D, the clients made additional requirements concerning the documentation in order to handle project complexity and gain a better overview, which resulted in more explicit documentation. In none of the projects, the interrelations between design decisions were documented, as these are regarded as logical derivatives of design activities which do not need explicit documentation. Project D is the only project in which the context was documented. This can be explained by the involvement of several project members in this project, who were also active in projects A and C. These projects were executed before the start of project D, thus the process is developed by learning from previous experiences. Summarized, there is little explicit documentation of design decisions, their interrelations, context and the rationale behind decisions in current practices.

#### *Who*

Table 2 suggests that responsibilities for documentation are assigned in two projects, but that this is not done structurally for the other two projects. The results of project A can be explained by the project's contextual complexity which could not be handled without assigning clear responsibilities. The results of project D can be explained by the clear focus on documentation in this project. Compared, documentation was not the focus of project C, hence responsibilities were not structurally assigned from the start. In project B, project members had much discussion on who should take responsibility for a specific task which deteriorated the division of responsibilities. Concluding, responsibilities for documentation are assigned in current practices, but doing this structurally for all aspects could be improved in some projects. Furthermore, the pattern match indicates that the responsibilities for monitoring the documentation are assigned in three projects. This suggests that these responsibilities are better considered in current practices than those for documenting itself. The case study results explain this by addressing the documents, as the integral design note, that serve as deliverables for the client. These documents are thoroughly checked and monitored by the discipline leaders and technical managers before they are submitted. Because of this approval approach, the responsibilities for monitoring the documentation are assigned and accountability is ensured. These documents do not have to be delivered to the client often in the current project phase of project B as the focus is on the timely development of the

contract specifications. This explains the absence of responsibilities for strict monitoring in this project. So, responsibilities for monitoring the documentation are considered in current practices.

#### *When*

Table 2 indicates that much improvement is needed in current practices concerning immediate documentation and periodical monitoring. First, the results show that documentation has not been done immediately but only if a required deliverable had to be developed. An exception was made in the explicit documentation of meetings in project D, which was done immediately to prevent an additional documentation activity later. No strict rules were set in any of the projects for immediate documentation. Therefore, this was not perceived as obligatory by the designers and as they also consider it time-consuming, it was not done. Second, periodical monitoring is largely absent in current practices as it is considered an additional time-consuming task in an already full project schedule. Only in project C, design meetings are used to discuss and monitor documentation, but this required a different demeanour and openness of all involved disciplines. Summarized, the process is not documented immediately in current practices. Periodical monitoring is applied very limited, while this would be a satisfactory approach to ensure this immediate documentation. Furthermore, Table 2 suggests that the assessment of all available documentation is only performed in one project. The case study results explain the absence of an assessment by addressing the hierarchy in collaboration between client and engineering consulting firms in practice. As the client procures the project assignment, the engineering consulting firm is considered to meet their requirements but not set these themselves. The standard procedure for documentation transfer of the client is considered sufficient by the project members in project B, but this has not resulted in a more complete documentation. To prevent redoing activities, the management of project D initiated a phase in which design activities were withheld until all required documentation was collected and assessed. The recent start of this project allowed the project team to learn from previous experiences and therefore persist in performing an assessment. To conclude, performing an assessment of all available documentation is upcoming in current practices.

#### *Where*

The pattern match suggests that the use of a pre-defined template in the documentation environment is partly covered in current practices. In projects A and B, a pre-defined template was not or partly used as the project management aimed to make documenting as

easy as possible for the user. In the other two projects, it was stressed that using a template benefits the quality of documentation. However, the freedom that project members have in documenting in the template in practice is large as fields could be left open and the manner of entering information was not restricted by the template. This is again explained by the perspective that following a strict template is considered too much effort. Summarized, a pre-defined template for documentation is used in current practices but the user has much freedom in its completion. Table 2 indicates that a good accessibility of the documentation for all involved project parties is considered in current practices. The case study results explain this by addressing the extensive use of a documentation environment especially made to ensure accessibility and traceability in large SE projects. This program is considered the standard in the civil engineering industry for projects with a large number of involved parties and was thus prescribed by the clients. In project B, information was mainly communicated in person which makes accessibility to this same information hard for other project parties. Concluding, a good accessibility of the documentation for all involved project parties is covered in current practices.

### *How*

The pattern match suggests that the visualization of design decisions and interrelations in their context is not yet structurally performed in practice. Although projects C and D do connect the decisions to the contextual geographical location in a design drawing, the interrelations are not accounted for. The absence of visualizations in the other two projects is explained by the lack of explicit documentation, which impedes developing good connections. In project B, decisions were listed per contextual object to create more overview and structure in the project, connecting the aspects in a more implicit manner. In project A, textual documentation was considered sufficient to determine which design element the design decisions affect. Summarized, design decisions are visualized in their context in current practices but this visualization should be complemented by the addition of interrelations.

### **Ranking the results**

As the pattern match (Table 2) indicates, large differences between the results of the different projects emerge. Project D seems to score best on most of the patterns, and project B never performs up to the theoretical standard. The analysis of the results was discussed in order of their place in the framework of documentation aspects what, who, when, where and how. Furthermore, the results were also ranked from most to least in correspondence with literature. Considering this ranking,

the following most important conclusions can be drawn:

1. Both good accessibility of documentation is considered (see Table 2-‘Where’-ranking 1) and clear responsibilities for monitoring documentation are assigned in three projects (see Table 2-‘Who’-ranking 2). Only in project B, no match between theory and practice could be observed for both these patterns. Two projects (A and D) are in keeping with theory concerning the division of responsibilities for documenting itself, and one is partly (C), see Table 2-‘Who’-ranking 3.
2. The use of a documentation environment with pre-defined template is applied in projects C and D and for a part of the aspects of the documentation process in project A (see Table 2-‘Where’-ranking 4). Project B is the only project that does not document any of the aspects as suggested in literature (see Table 2-‘What’-ranking 5). For the visualization of design decisions and interrelations in their context, project A is the only project without any correspondence with theory (see Table 2-‘How’-ranking 6).
3. Only in project D, a match between theory and practice could be observed concerning the documentation assessment. The other projects are only partly (B) or not in keeping with literature, see Table 2-‘When’-ranking 7. Immediate documentation and periodical monitoring was performed in some situations in projects C and D, but none of the projects showed practices comparable to theory (see Table 2-‘When’-ranking 8).

### **General overview and explanation**

Concluding, good accessibility of documentation is currently considered in practice as clients require the use of a specific environment that contributes to traceability and structure in handling large SE projects. The analysis also indicates that assigning responsibilities for both documenting and monitoring this documentation is done in current practices as it is required to handle the projects’ complexity. A pre-defined template for documenting design decisions is used to an increasing extent to improve the quality of documentation, however users are given much freedom in completing it. The client plays an important role in the presence of explicit documentation as this is more complete when the client puts emphasis and focus on documentation. The documentation of design decisions and rationale is considered in current practices but the context of and interrelations between design decisions are not documented. The design decisions have been visualized in their context in some projects, however this could be complemented by additionally developing a visualization of the interrelations. The largest differences between current practices and literature are identified



in performing a documentation assessment, periodical monitoring and immediate documentation. Assessing previous documentation is considered difficult in practice because of the difference in power position of the client and engineering consulting firm. Currently, hardly any strict procedures for the moment of documentation are applied resulting in postponement of these tasks due to time-pressure.

### **Additional findings**

In the interviews performed during the case studies, additional data were collected that were not used in the pattern matching analysis. These data provided the researcher with a better understanding of the specific approaches that are already used or are absent in current practices. First of all, the project members stressed that indications for when a design decision needs to be documented are required. Document analysis showed that a design decision should be documented if it deviates from the design norms and standards, if it affects other design decisions and if it leads to choosing a specific design alternative. Furthermore, documentation has to be performed in four types of documentation activities: for design activities, process-determining decisions or during design and technical management meetings. Besides documenting the design decisions, the findings stress that subsequently discussing the documentation during meetings is the only manner in which everyone becomes familiar with the contents. Furthermore, project members indicated that often, based on experience, an overview of design decisions that will need to be made in a project phase could be developed already at the start of that phase. This enables a better overview of the design decisions and dependencies in terms of project schedule, and provides structure for those responsible.

## **5. DEVELOPMENT OF A CONCEPT STRATEGY**

This section describes the development of a concept strategy, based on the performed pattern matching analysis. In line with the aspects distinguished in literature, the concept strategy describes *what* should be documented, *who* is responsible, *when* it should be documented, *where* it should be documented and *how* it should be documented. The pattern match of each case shows an overview of the similarities and differences between theoretical and empirical patterns. The case studies thus provide insight in the elements already covered in current practices, and those which could still improve. Also, the findings indicate the relevance of and cohesion between these elements in practice.

Considering the extent of these improvements, it may not be feasible to successfully implement the concept strategy in a project organization at once. Therefore, the concept strategy introduces different levels that should be implemented subsequently. In the levels, the different elements of the strategy are discussed, categorized under the documentation aspects what, who, when, where and how. Per level, a more extensive description is presented that explains the required steps to acquire that level of the strategy. This provides a practical perspective on the concept strategy for the studied engineering consulting firm, which improves its applicability for implementation in a project organization.

At first, the concept strategy addresses the base situation, which resembles the current practices that follow from the case studies. As this level might not be current practice for each project, these elements of the strategy are also explained more in-depth. Subsequently, three levels are presented that can only be implemented in that specific order. The researcher determined the content of the different levels based on the results of the case studies. Important for establishing the order was the ranking of the elements, based on the correspondence of practice and theory.

### **Underpinnings for the concept strategy**

Based on the outcomes of the pattern match analysis, the distribution of the strategy elements across the different levels of the concept strategy was made by the researcher. This paragraph describes the underpinnings for the development of the concept strategy.

The three elements that are generally included already in current practices, good accessibility (see Table 2-‘Where’-ranking 1) and responsibilities for both documenting and monitoring this documentation (see Table 2-‘Who’-ranking 2 and 3), are addressed in the base level.

Subsequently, the documentation of design decisions and rationale is included in the first level. This is because these elements are already partly implemented (see Table 2-‘What’-ranking 5), however also because these elements form the foundation required for the implementation of all other strategy elements. Furthermore, the use of a pre-defined template is implemented in this level as results show it facilitates the documentation of design decisions and rationale. At last, immediate documentation and periodical monitoring will have to be acquired in this level even though its performance is a large step from current practices (see Table 2-‘When’-ranking 8). It is considered essential for improving the documentation of design decisions and therefore it should be implemented at the start of improving the documentation process.

In the second level of the concept strategy, the documentation of interrelations and context of design decisions is addressed. Implementing these aspects requires a better understanding of the project system by the user than is required for a design decision itself. Furthermore, the results show that the design decisions and justification will need to be documented before these aspects could be documented. If these elements are documented, the visualization of design decisions and interrelations in their context could be considered.

In the third level, the assessment of all available documentation is addressed. Findings indicate that performing this effectively could only be achieved if the assessors have a good understanding of what documentation should be available and what quality this should have. To acquire this knowledge, the previous levels will have to be mastered first. Therefore, this strategy element can only be performed if all other elements of the strategy are already implemented.

### Specifications of the concept strategy

This paragraph describes the specifications of the concept strategy, of which a summarized version can be found in Table 3. In Appendix All, Figures A.1-A.6 show the extensive concept strategy, in the format in which it was presented to the participants of the validation sessions. The extensive descriptions of the elements in the different levels are based on the additional data collected in the case studies. The different strategy levels are visually presented in Figure 1.

### Current practices

First, suggestions for ensuring good accessibility for all involved project parties are described. The concept strategy explains the importance of a shared

documentation environment. Furthermore, it describes the possibility of applying different user restrictions based on involvement in specific activities and project phases. Second, the importance of assigning responsibilities for monitoring documentation is stressed. As the results indicated, performing the monitoring with two people is considered necessary. The discipline leader is responsible for the first approval and the technical manager for the second. The concept strategy follows this distribution of responsibilities, considering its effective implementation in current practices. Third, also the distribution of responsibilities for documenting itself is described. The concept strategy suggests a distribution of responsibilities for different documentation activities that were identified in the case studies.

### Level 1

First addressed in this level is the documentation of design decisions and rationale. Although these aspects are considered in current practices, this is too little and mostly implicit as the cases showed. As documenting all design decisions is considered not desirable, indications for when a design decision needs to be documented are described. Furthermore, at the start all known design decisions that will have to be made during the project have to be documented already. For the rationale, the format in which this justification should be documented is described. Secondly, the pre-defined template in which these design decisions and rationale should be documented is addressed. The specifics of this template are suggested, based on the documentation elements described in the concept strategy. Third, this level indicates the importance of immediate documentation and periodical monitoring. The concept strategy distinguishes documentation during design activities and during meetings.

**Table 3:** The concept strategy.

<b>CURRENT PRACTICES</b>	<b>Where</b>	Ensure good accessibility of documentation for all involved project parties
	<b>Who</b>	Assign clear responsibilities for documentation to a specific person
		Assign clear responsibilities for monitoring documentation to a specific person
<b>LEVEL 1</b>	<b>What</b>	Design decisions
		Justification for the design decision
	<b>Where</b>	Document design decisions and their justification in a pre-defined template
	<b>When</b>	Document the design decisions and justification immediately
<b>LEVEL 2</b>		Perform periodical monitoring
	<b>What</b>	Interrelations between design decisions
		Context of the design decision
	<b>How</b>	Place design decisions in a geographical location
<b>LEVEL 3</b>		Make a network of design decisions
	<b>When</b>	Perform an assessment of all available documentation at the start of a new project phase

### Level 2

The documentation of interrelations and context design decisions is first discussed. The user is guided in steps from defining the interrelations to documenting these and adding a rationale for the relation specifically. This justification is required as the findings demonstrated it is often unclear why decisions are related and how one affects another. Similar steps are included for defining and documenting the context of a design decision. Second, these new aspects of documentation should be visualized. The settings for these visualizations are to be accounted for by the software manager, so the description focuses on the implications for the project members and how the visualizations could be used in practice.

### Level 3

The assessment of all available documentation at the start of a new project phase is addressed. The concept strategy describes the steps that will have to be performed during this assessment. It is important that all design activities are postponed until the assessment is finished. Furthermore, the aspects on which the assessment should focus are listed in this level.

## 6. RESULTS: VALIDATION OF THE CONCEPT STRATEGY

This section summarizes the results of the validation of the developed concept strategy, which is shown in Table 3 and Figure 1. In this validation, the concept strategy was assessed by different experts. The extensive results can be found in Appendix AIII, Table A.5. Because of readability, the table in Appendix AIII represents only a selection of the most significant quotes given in the interviews to support the results. A summary of the results is given in the next section, focusing first on the validation of the concept strategy in general. Subsequently, the most important results of the validation of the strategy levels specifically are discussed.

### General overview

The results of the validation indicate that the use of the five documentation aspects (what, who, when, where and how) as structure for the strategy is considered positive. This structure evokes recognition among the experts and thus lowers the threshold for implementation of the strategy. Some participants did indicate that intuitively it would be more logical to address all five aspects in every level but in different gradations, as there for example will

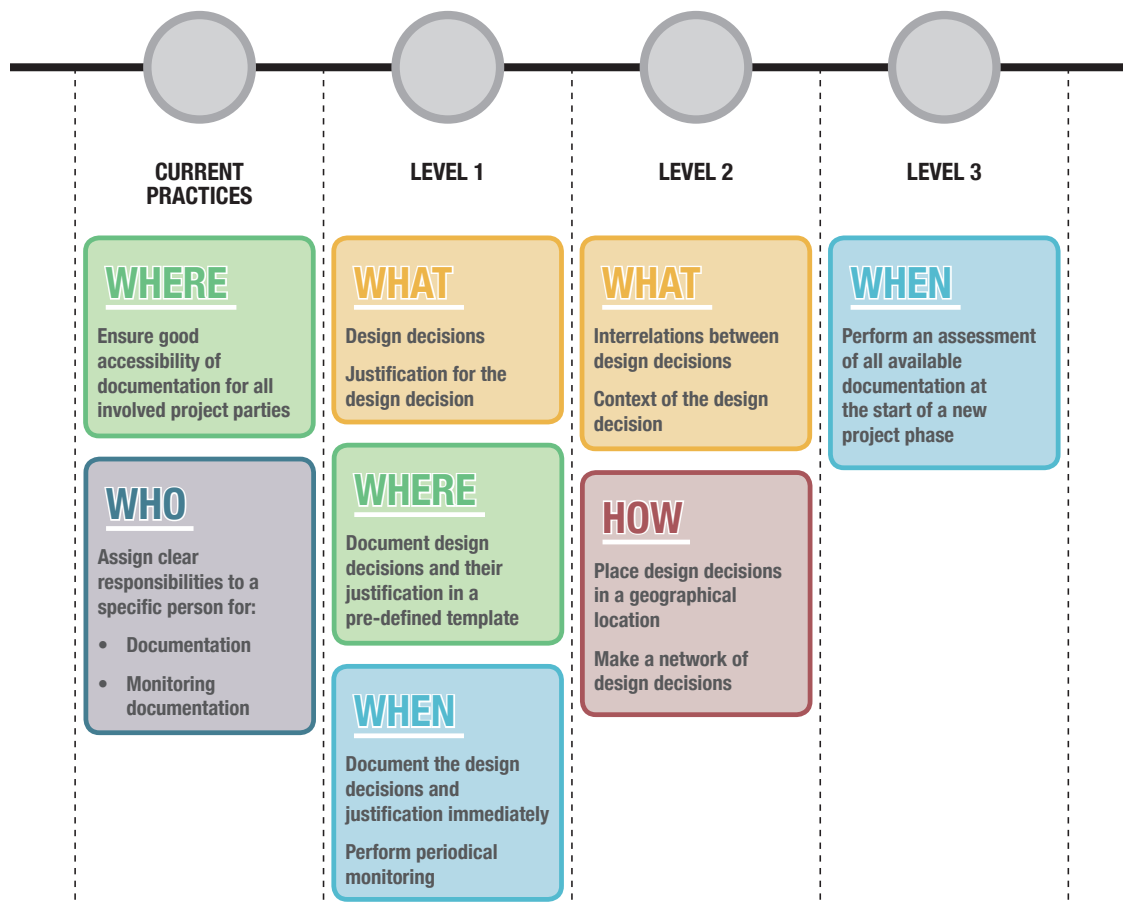


Figure 1: The concept strategy, showing the strategy levels and corresponding elements.

have to be someone responsible in all levels. The use of different levels and the order in which the different elements are supposed to be implemented is chosen well according to the participants. The content of the different levels is clear and the manner in which the elements are combined is logical.

Participants acknowledged that it would not be possible for every project organization to implement all levels because of limitations in its budget, schedule, or size of the team. Therefore, they argued that the project team should discuss acquiring a certain level in a first meeting of the project. Besides determining the project ambition concerning the strategy, the experts suggested to specify the strategy in two formats for both small and large projects. The validation confirms that the perspective of the client is decisive for a successful implementation of the strategy. The more focus the client puts on documentation, the more extensive the documentation process will be according to the experts.

### **Strategy levels**

All participants agreed that in general, the elements described in the base level are performed in current practices. However, two of them argue that this is mainly for infra- and construction projects and less for the water disciplines. The importance of determining the levels to be acquired specifically per project is stressed again, as it would require more effort for water projects to implement the entire strategy. The perceived bottleneck for applying this level in practice is an undue required effort for small projects.

The experts found the indications for when to document a design decision in the first level logical and clear. They suggested some additions to cover all possible decisions; if the involved costs or risks of a decision are high, if it affects requirements or if it changes the functionality. Furthermore, they stress the importance of a fully equipped template as this is necessary to facilitate the elements described in the first level.

Besides that, the implementation of SE in the project should have the same decomposition as the documentation structure as otherwise the visualizations of the second level cannot be constructed. All experts were positive on visualizing the design decisions and interrelations, as they argued this indeed improves the overview and insight of project members. Also, they indicated the visual representations as beneficial for communication with the client and other stakeholders.

For the third level, it was argued that the assessment could be performed in different levels matching the elements described in the strategy's levels. However, the participants did see the, in practice often tight, project schedules as bottleneck for the successful implementation of this level.

## **7. COMPARISON TO EXISTING LITERATURE**

This section compares the case study results of this research with existing literature, to support previous findings and to demonstrate differences. Furthermore, it compares the findings of this study concerning the implementation of a strategy for the documentation of design decisions to previous literature.

This research shows that explicit documentation of design decisions is important for the successful development of a civil engineering project, but also that current practices require many alterations before this documentation is up to theoretical standard. In line with the studies of Elliot (2012), van Houdt & Vrancken (2013) and Luo et al. (2017), the results show that this documentation is especially important in the transition of information between different disciplines and organizations. Yet practice shows that especially on these transitions, documentation is often not up-to-date and delivery to others is too late. Furthermore, the existence of documentation proves not to be enough for all project members to be aware of the design decisions. The importance of discussing the decisions with the entire team is thus stressed, specifically in case of transitions between different disciplines (Jansen et al., 2008).

Also, the findings are in line with others in showing that the use of SE does not ensure a complete and successful procedure for this documentation (van den Houdt & Vrancken, 2013; van der Meer et al., 2015). However, the results also suggest that SE was not always applied to its full potential in practice. This research also reveals that project teams struggle with determining the requirements for documenting a design decision. Project members agree with Weinreich et al. (2015) that a distinction should be made in the documentation process, as it is considered not feasible to document every design decision. Additionally, the findings are in line with the study of Tyree & Akerman (2005) in indicating that design decisions could be used for giving direction in the development process. A set of design decisions that will need to be made in a project phase could already be developed at the start, based on experience.

This research introduces a strategy for the documentation of design decisions in civil engineering projects and shows that the implementation of such a strategy in a project organization comes with certain difficulties. The civil engineering industry's high time-pressure, project-oriented and task-focused culture impede many to make the required investments in documentation (Noordin et al., 2012; van der Meer et al., 2015). Also the attitude of the designers towards a change in the standard manner of working is a bottleneck for sufficient documentation of design decisions (van den Houdt & Vrancken, 2013). Therefore, the implementation



of a strategy should not be performed at once but in different levels that build up to a complete documentation. This implementation has to adapt to the large number of involved project parties and different phases in the projects (Farnham & Aslaksen, 2009).

## **8. LIMITATIONS**

This research does have some limitations that should be pointed out. First, the pattern match only scores current practices relative to the theoretical framework as this research did not study the performance of the different projects in terms of budget, client satisfaction or compliance to the schedule. It was not the intention to study the relation between the degree of documentation and project outcomes. The intention was to identify potential improvements in the documentation of design decisions with the framework and to develop a strategy for the engineering consulting firm. However, it is a recommendation for future research to study the relation between the degree of documentation of design decisions and project outcomes.

Second, the projects used for the case studies are all large road infrastructure projects of the same engineering consulting firm and client, chosen to minimize confounding variables. Also, only four projects were studied in this case study research. This reduces the generalizability of the findings for different types of projects and other sorts of companies. As this research aims to propose a strategy for all types of civil engineering projects, the validation was done with experts working for different clients and specialized in different types of disciplines as for example flood defences. Although this validation improves the generalizability of the developed strategy, this also brings forward the third limitation of this research. The validation was performed with only five participants, all from the same engineering consulting firm as the participants of the case study interviews. Therefore, future research is recommended in which the strategy is validated with a larger group of participants who are representative for the entire civil engineering sector. Different companies from the sector should be included as for example contractors, instead of one engineering consulting firm as was studied in this research. Suggested is also an additional long-term research in which the strategy is actually implemented in a pilot project, preferably focused on a different discipline than road infrastructure and in which the client is for example a municipality, province or private sector organisation.

The last limitation of this research is the diversity in project phases of the different case study projects. The case studies were selected partly based on this diversity,

so that an extensive overview of current practices could be developed. However, the nature of a project phase could affect the extent, explicitness and approach towards the documentation of design decisions. This diversity in project phases had a large influence on the involvement of the engineering consulting firm and their relation with the client. Furthermore, the focus of the client was more on documentation in the early phases of the projects. As both the client's focus and the hierarchy between these two parties influence the documentation, the differences in phases of the case study projects could have influenced this study's findings. Additional research is required to establish more insight in the relation between the project phase and the documentation of design decisions.

## **9. CONCLUSION**

The documentation of design decisions is important as it provides insight in what decisions have been significant in the project development. However, little attention is paid on this documentation in SE or civil engineering literature. This research was conducted by request of a civil engineering consulting firm, that observed problems concerning the documentation of design decisions in their projects. These problems are also acknowledged in some studies, especially at the transitions between project phases or different involved parties. Project members do not receive the required information, or it is provided too late delaying work activities. Furthermore, approaches and formats differ per organization or team, which makes tracing information a tedious and time-consuming task. At last, discussions in projects are repeated multiple times as no documentation can be provided based on which the discussion could be closed.

To identify the current practices concerning the documentation of design decisions in the context of Systems Engineering, this research was conducted. Furthermore, it aimed to develop a strategy for improving the documentation process which could be implemented in the engineering consulting firm.

### **Research method**

To study current practices, a theoretical framework was developed based on existing literature of both the civil engineering and other sectors. First, the importance of documenting both design decisions and their rationale, interrelations and context is addressed. This provides a justification of why a decision has been made, but also shows the decision in relation to other decisions and its context. The responsibilities for both documenting and monitoring documentation should be given to a specific person, according to literature. The use of an

environment in which the user can document in a pre-defined template is recommended to ensure uniform documentation. Furthermore, good accessibility for all organizations involved is very important as civil engineering projects have a large number of involved project parties. To guarantee complete documentation, design decisions should be documented immediately and this should be monitored by periodical reviews. An assessment of previous documentation is recommended to be done at the start of each project phase to provide a baseline of all available information.

Then, this framework was compared to four road infrastructure SE projects to study the similarities and differences between current practices and theory. Thereafter, these findings were used to develop a concept strategy which was validated by experts who work in different disciplines of the civil engineering sector.

### **Research findings**

The findings demonstrate that good accessibility of documentation for all involved project parties is already considered in current practices. This is mainly because of the requests made by the client for the use of a specific environment that contributes to ensuring structure and traceability in large SE projects. Furthermore, the division of responsibilities in practice for both documenting and monitoring this documentation are in keeping with theory. Project members explained these results by indicating that assigning these responsibilities was required to be able to handle the projects' complexity.

The documentation environments used in practice do provide pre-defined templates to document design decisions, but these templates leave more freedom to the user than those described in literature. Design decisions are documented in some of the projects studied, but often incomplete and without rationale that explains why the decision was made. These aspects were most complete in the project that started most recently. Project members who also participated in some of the other case study projects, indicated that they learned from previous experiences of those projects. Interrelations between design decisions and a decision's context, as described in literature, are missing in current documentation processes in practice. The suggestions that were provided in literature for visualizing the decisions in their context are observed in practice, but this could be complemented by additionally developing a visualization of the interrelations.

Assessing all previous documentation at the start of a new project phase is only done in the project that started most recently. Based on previous experience, this project team persisted in performing this assessment to prevent redoing activities. Other projects indicated that the assessment is considered difficult in practice

because of high time pressure and the difference in power position of the client and engineering consulting firm. The moment of documentation is not in keeping with theory, as documenting is not done immediately. Also, no periodical monitoring is performed in practice that could ensure this immediate documentation.

### **Strategy for the documentation of design decisions**

Because of the extent of the improvements following from the case studies, it is considered difficult to implement the strategy in a project organization at once. Therefore, the elements are assigned to different levels that should be implemented subsequently. The base level describes the current practices at the engineering consulting firm being good accessibility of documentation and division of responsibilities. In the first level, the documentation of design decisions and their justification, the use of a pre-defined template, immediate documentation and periodical monitoring are explained and suggestions for their implementation are provided. The second level addresses the documentation of interrelations and context of design decisions, and possibilities for visualizing these aspects. The third level considers an assessment of all available documentation at the start of a new project phase.

Validation of the concept strategy shows that project members consider it hardly possible to implement all strategy levels in every project, because of possible limitations in its schedule, budget or size of the project organization. Therefore, a project team should discuss the ambitions of acquiring a specific level in an opening meeting of the project. The validation also indicates that the strategy itself should be specified separately for both small or large projects. Future research should be performed to determine the differences in specifics. The validation shows that the current practices in infra- and construction projects are more in keeping with theory than those in water disciplines. For this latter field, the base situation described in the strategy is not yet acquired. Furthermore, the attitude of the client is considered very important for a successful implementation of the strategy. If the client emphasizes the importance of documentation and thus requests this to a large extent, the documentation elements will be executed more extensively.

To ensure successful application of the strategy, barriers that could obstruct the implementation should be deducted or studied further. Tight project schedules form a threat to a successful implementation of the strategy. For example, performing the assessment of documentation would be obstructed as the deadlines require the design activities to commence already. Future research should prove the positive influence of such an assessment on the project performance, so that the

reclassification of time could be argued. Furthermore, the attitude of the designers is considered a possible barrier. They might perceive the documentation process described in the strategy as an administrative burden which distracts them from their design tasks, and thus obstructs them from performing it.

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## APPENDIX I.

Table A.1: Pattern match Project A.

Framework	Theoretical patterns	Empirical patterns	Match	Explanation
<b>What</b>	There should be documentation of design decisions and their interrelations, context and the rationale behind decisions	There is limited explicit documentation of design decisions and rationale is only implicitly documented. No interrelations or context of design decisions are documented	o	Design decisions and rationale are documented implicitly in specific reports as this was requested by client. There were no requirements set for explicit documentation in Relatics, so due to time pressure and short-term deadlines this was not done to a large extent. Interrelations are regarded as logical derivatives of design activities, thus were not documented specifically
<b>Who</b>	There should be clear responsibilities assigned for the documentation	Responsibilities for documentation are assigned to specific people	+	Responsibilities were assigned to prevent elements of the project not being accounted for. However, this responsibility was for the documentation in the final reports
	There should be clear responsibilities assigned for monitoring the documentation	Responsibilities for monitoring the documentation are assigned to specific people	+	Responsibilities were assigned to prevent elements of the project not being accounted for. However, this responsibility was for monitoring the documentation in the final reports
<b>When</b>	There should be immediate documentation of design decisions, rationale, interrelations and context which should be ensured by periodical monitoring	Documentation is not done immediately and no periodical procedure for monitoring was used	-	Designers perceive the immediate documentation as administration without obvious benefits, so they are not willing to change to that new manner of working even though management would prefer it. No hard rules for moment of documentation are set
	There should be an assessment of all available documentation performed at the start of a new project phase	No assessment of all available documentation was performed at the start of a new project phase	-	An assessment of all documentation has not been performed as the engineering consulting firm is considered not to be in the position to set requirements for the client at that moment
<b>Where</b>	There should be a documentation environment in which the user should document in a pre-defined template	The design decisions are documented in Relatics in a template, and in free form in meeting minutes and reports	o	Administrators of Relatics decided to specify several fields in the template to ensure uniform documentation. However, user is free to leave parts of template open. In reports, users could document in his own manner as this is considered most easy for them
	There should be good accessibility of the documentation for all involved project parties	The program Relatics ensures good accessibility of the documentation for all project parties	+	Relatics is considered as standard in the industry for management large SE projects, so its use was prescribed by the client
<b>How</b>	There should be a visualization of the design decisions and interrelations in their context	Design decisions are not placed in context but only documented as derivative of meetings or implicitly in text, interrelations are not documented at all	-	Textual documentation was considered sufficient to determine to which element of the design the decisions belong

**Table A.2:** Pattern match Project B.

Framework	Theoretical patterns	Empirical patterns	Match	Explanation
<b>What</b>	There should be documentation of design decisions and their interrelations, context and the rationale behind decisions	There is only implicit documentation of design decisions and rationale is missing. No interrelations or context of design decisions are documented	-	The project team was not focused on traceability of information in the early phases of the project and thus did not document extensively. Interrelations and context are regarded as logical derivatives of design activities, thus were not documented specifically
<b>Who</b>	There should be clear responsibilities assigned for the documentation	Responsibilities for documentation are not clearly assigned to specific people	-	Because documentation was considered less important in design phases no responsibilities were assigned. In the contract development, actions do have responsible persons but these are not focused on documentation
	There should be clear responsibilities assigned for monitoring the documentation	No responsibilities are assigned for monitoring the documentation	-	In the contract development, focus is on delivering specifics contract and thus not on documentation and monitoring
<b>When</b>	There should be immediate documentation of design decisions, rationale, interrelations and context which should be ensured by periodical monitoring	Documentation is not done immediately and no periodical procedure for monitoring was used	-	Designers do not think the benefits of immediate documentation outweigh the effort and time it takes. No hard rules for moment of documentation are set
	There should be an assessment of all available documentation performed at the start of a new project phase	Standard RWS procedures are used for assessment of some documentation at the start of a new project phase	o	The RWS procedures (gates and KAD), focusing on the most important design documents, are considered sufficient for assessing necessary documentation according to management
<b>Where</b>	There should be a documentation environment in which the user should document in a pre-defined template	The design decisions are documented implicitly and in free form in memos and meeting minutes	-	In memos and meeting minutes, users could document in his own manner as this is considered most easy for them
	There should be good accessibility of the documentation for all involved project parties	Not all required documentation could be traced by project members	-	As traceability of information was not considered in early project phases, this documentation is missing or hard to trace by current project members
<b>How</b>	There should be a visualization of the design decisions and interrelations in their context	A selection of design decisions is captured in posters of objects in context, interrelations are not documented at all	o	To structure the project and gain overview, posters are made for each object in which the most important decisions are discussed

**Table A.3:** Pattern match Project C.

Framework	Theoretical patterns	Empirical patterns	Match	Explanation
<b>What</b>	There should be documentation of design decisions and their interrelations, context and the rationale behind decisions	There is documentation of design decisions and rationale. No interrelations or context of design decisions are documented	o	The traceability of design decisions and rationale was not considered in the design project phases, so documentation is done at a later moment as justification of the design was required by client. Interrelations and context are regarded as logical derivatives of design activities, thus were not documented specifically
<b>Who</b>	There should be clear responsibilities assigned for the documentation	Responsibilities for documentation are assigned to specific people for a large part	o	Responsibilities were assigned to prevent elements of the project not being accounted for. However, some elements do not have a specific responsible person for documentation because of lack of discipline
	There should be clear responsibilities assigned for monitoring the documentation	Responsibilities for monitoring the documentation are assigned to specific people	+	Responsibilities were assigned to prevent elements of the project not being accounted for. However, this responsibility was generally for monitoring the documentation in the final reports as the documentation was not fully explicit
<b>When</b>	There should be immediate documentation of design decisions, rationale, interrelations and context which should be ensured by periodical monitoring	Documentation is not done immediately, but documentation is monitored by discussion in design meetings	o	In two-weekly design meetings, design decisions have to be discussed and are at least documented then, documentation is not done immediately because of lack of discipline and time
	There should be an assessment of all available documentation performed at the start of a new project phase	No assessment of all available documentation was performed at the start of a new project phase	-	An assessment of all documentation has not been performed as the engineering consulting firm is considered not to be in the position to set requirements for the client at that moment and feels they should be able to trust the client in this
<b>Where</b>	There should be a documentation environment in which the user should document in a pre-defined template	The design decisions and rationale are documented in a pre-defined template of lines of reasoning	+	For the lines of reasoning a template was discussed to ensure that all elements were documented at the same level. However, the exact completion of the templates was different for each discipline as else it would require too complex alignment
	There should be good accessibility of the documentation for all involved project parties	Procedure for storage documentation ensures good accessibility for all project parties	+	Communication between different project parties was considered very important, so focus was put on good accessibility of all documentation
<b>How</b>	There should be a visualization of the design decisions and interrelations in their context	Design decisions are connected to the contextual geographical location, interrelations are not documented at all	o	Design decisions are connected to the location in design drawings to create insight in the context of the decision

**Table A.4:** Pattern match Project D.

Framework	Theoretical patterns	Empirical patterns	Match	Explanation
<b>What</b>	There should be documentation of design decisions and their interrelations, context and the rationale behind decisions	There is documentation of design decisions, rationale and context. No interrelations of design decisions are documented	o	Design decisions, rationale and context are documented explicitly as traceability was in the project focus from the beginning due to the level of innovation required in the project. Interrelations are regarded as logical derivatives of design activities, thus were not documented specifically
<b>Who</b>	There should be clear responsibilities assigned for the documentation	Responsibilities for documentation are assigned to specific people	+	Responsibilities were assigned to prevent elements of the project not being accounted for. The explicitness of documentation improved assigning responsibilities
	There should be clear responsibilities assigned for monitoring the documentation	Responsibilities for monitoring the documentation are assigned to specific people	+	Responsibilities were assigned to prevent elements of the project not being accounted for. The explicitness of documentation improved assigning responsibilities
<b>When</b>	There should be immediate documentation of design decisions, rationale, interrelations and context which should be ensured by periodical monitoring	Documentation is done immediately during meetings, during design activities it is not. No periodical procedure for monitoring was used	o	Meetings are directly documented in Relatics to prevent additional documentation activities afterwards. For other documentation, designers perceive the immediate documentation as administration without obvious benefits, so they are not willing to change to that new manner of working even though management would prefer it. No hard rules for moment of documentation are set
	There should be an assessment of all available documentation performed at the start of a new project phase	An assessment of all available documentation was performed at the start of a new project phase	+	Management instructed that the design could not start until all required documentation was collected and assessed, to prevent unnecessarily redoing activities
<b>Where</b>	There should be a documentation environment in which the user should document in a pre-defined template	The design decisions are documented in Relatics in a template	+	Administrator of Relatics decided to specify several fields in template to ensure uniform documentation. However, user is free to leave parts of template open
	There should be good accessibility of the documentation for all involved project parties	The program Relatics ensures good accessibility of the documentation for all project parties	+	Relatics is considered as standard in the industry for management large SE projects, so its use was prescribed by the client
<b>How</b>	There should be a visualization of the design decisions and interrelations in their context	Design decisions are connected to the contextual geographical location, interrelations are not documented at all	o	Design decisions are connected to objects in Relatics which are visualized in the GIS viewer to create insight in the context of the decision



## APPENDIX II

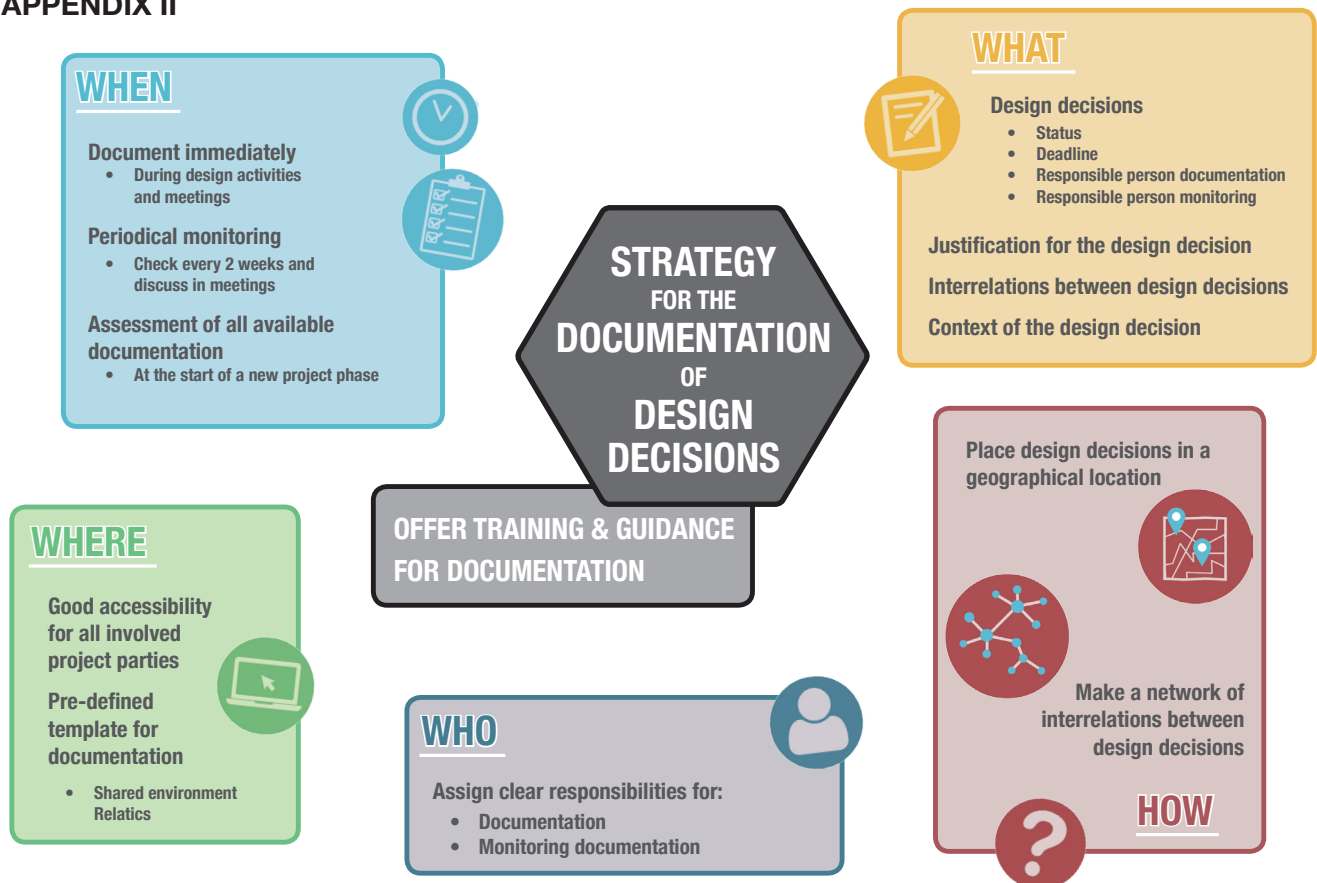


Figure A.1: Overview of the concept strategy.

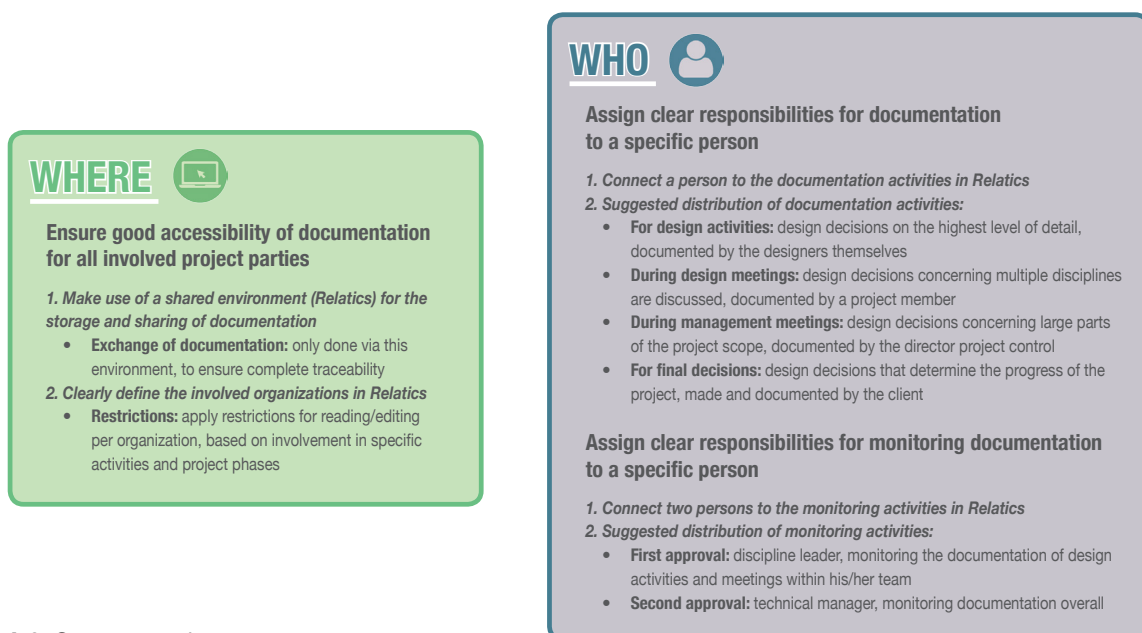
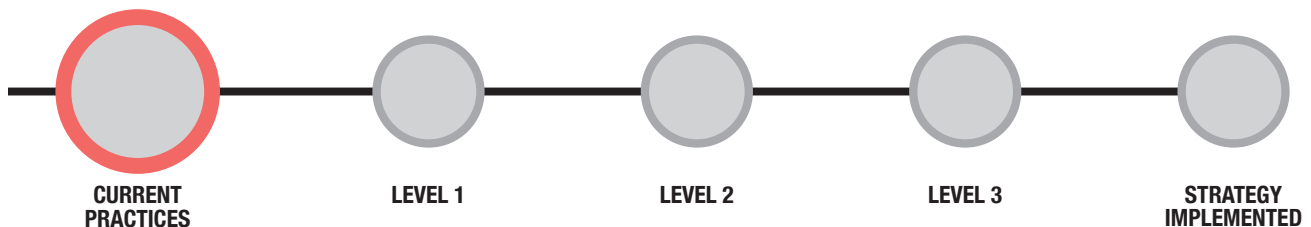


Figure A.2: Current practices.

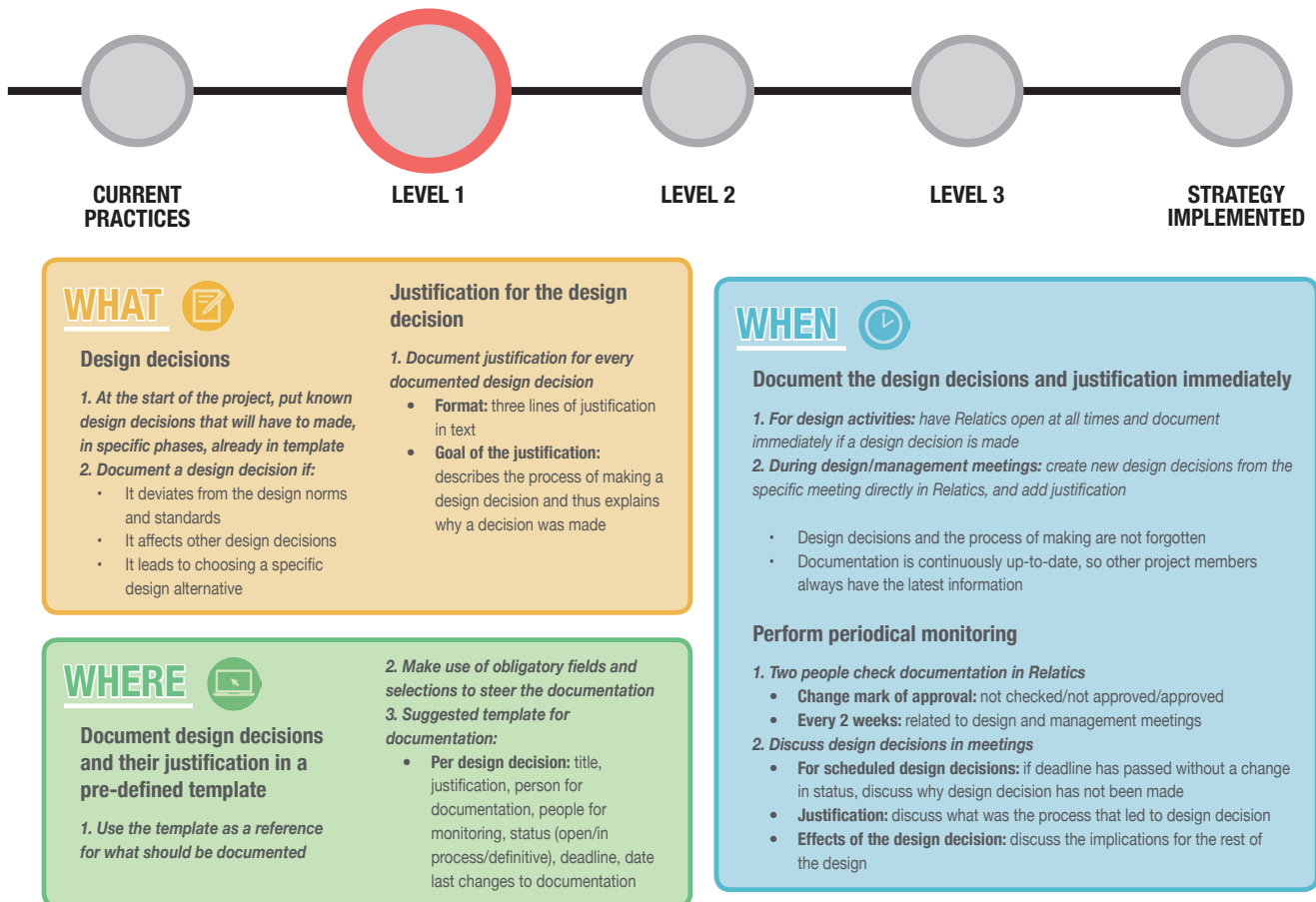


Figure A.3: Level 1.

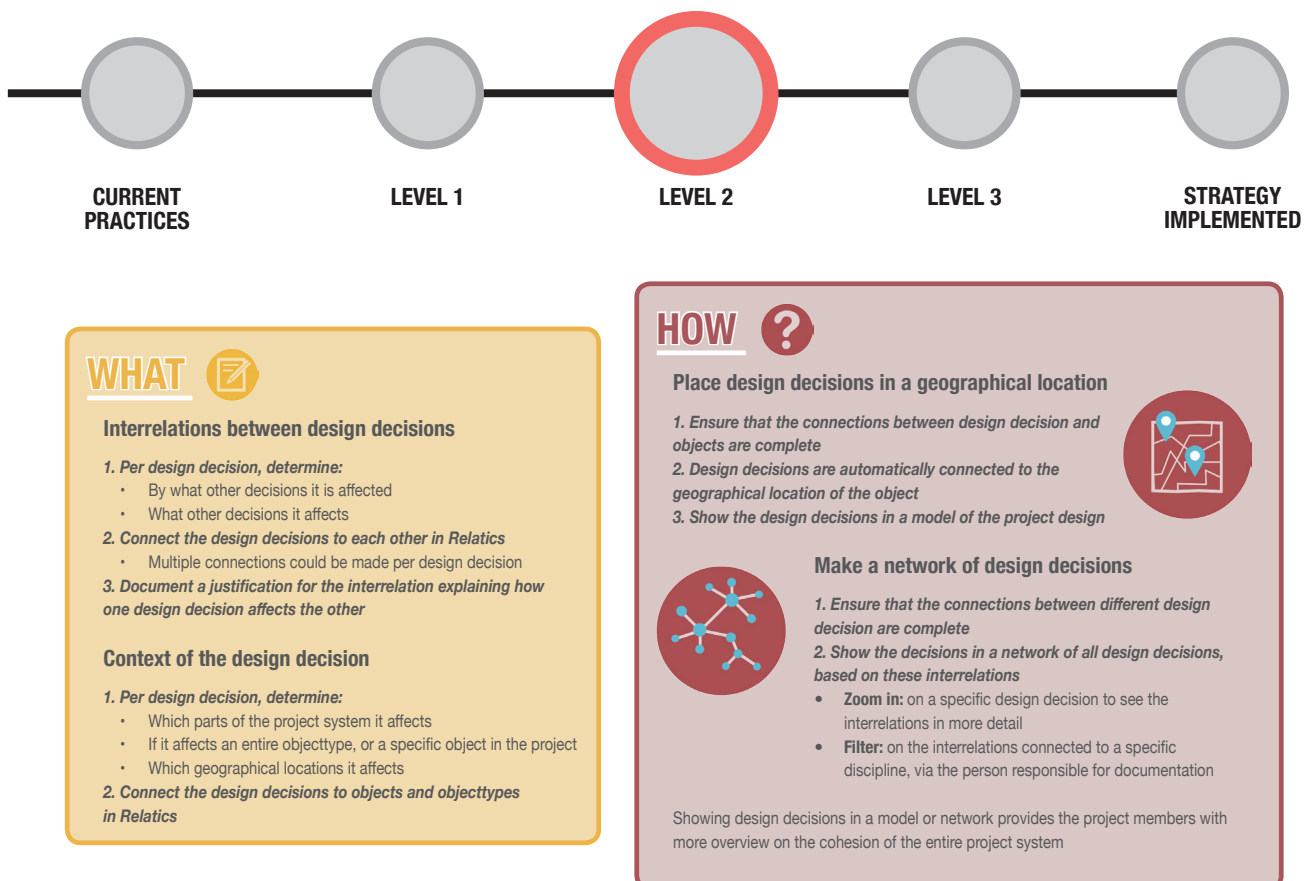


Figure A.4: Level 2.

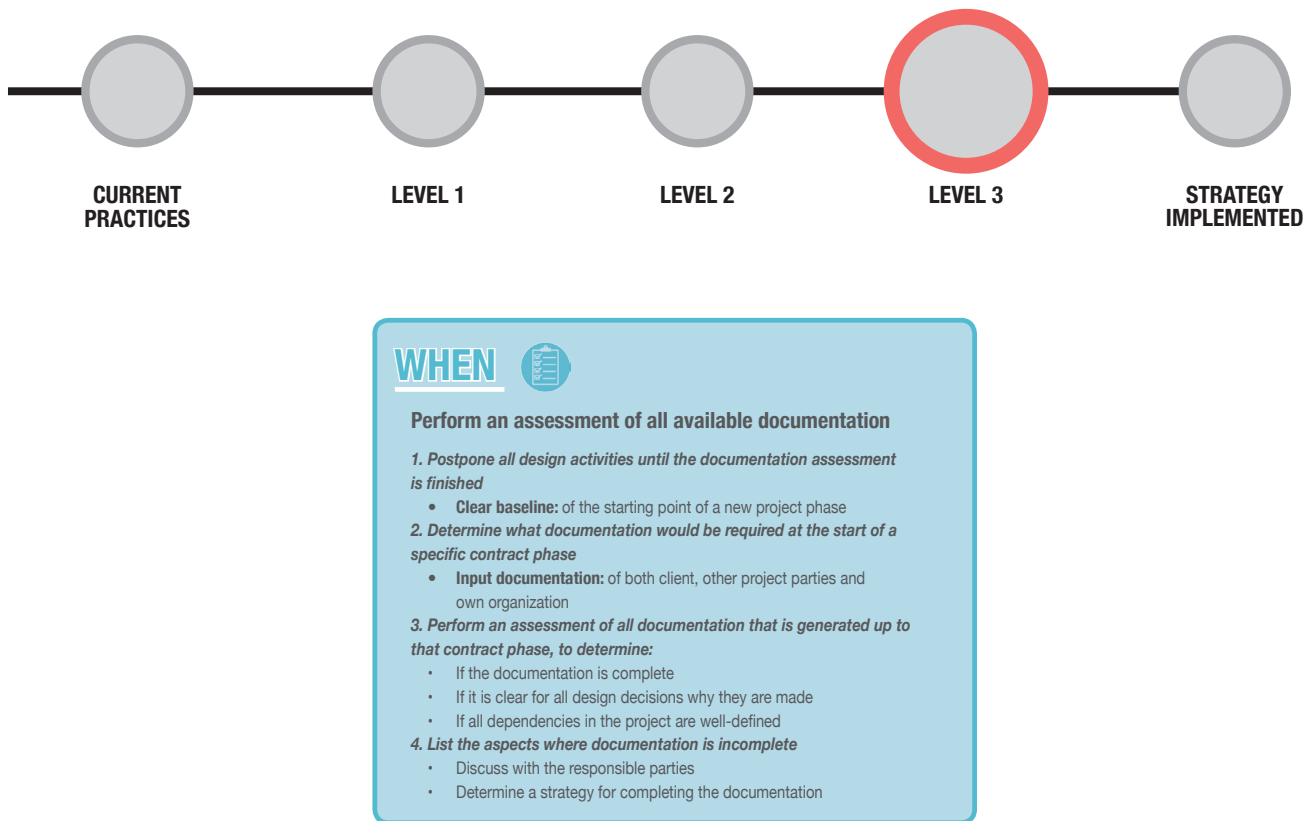


Figure A.5: Level 3.

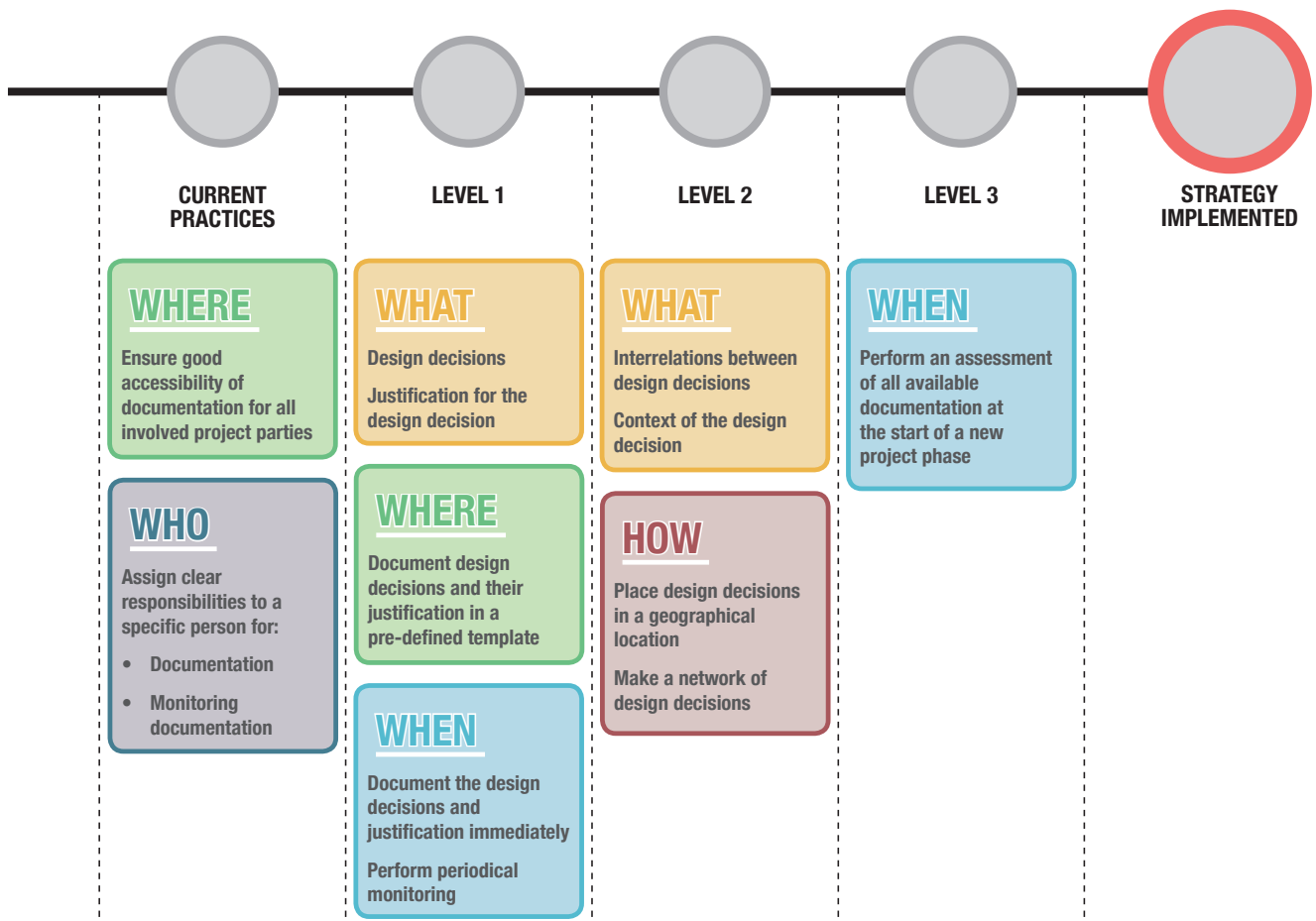


Figure A.6: Roadmap of the concept strategy,

## APPENDIX III

**Table A.5:** The summarized results of the validation of the concept strategy.

Validation part	Results	Quotes
<i>General overview</i>		
First impression of the concept strategy	Participants think the use of the five documentation aspects (what, who, when, where, how) is suitable. They do feel that the concept strategy should be adapted specifically to different project sizes. The elements look familiar, but are not structurally and explicitly performed in current practices. Participants are divided regarding the focus on the program Relatics in the concept strategy, two feel that this could also be other environments but the others are convinced of its use.	<p>"The use of those five pillars is very strong."</p> <p>"This reminds me of the review process of our firm, because of the levels."</p> <p>"I see elements in the strategy that we already try to implement in our projects, but far not explicit enough."</p> <p>"The usefulness of the strategy would perhaps improve if you make a distinction between small and large projects."</p> <p>"Everything is specified for implementation in Relatics now, but I think that for smaller projects other environments like Excel would also be fine."</p> <p>"Very good to strive for complete implementation in Relatics, that is really necessary."</p>
Order of implementing the elements	All participants agree that the order of the elements and distribution across levels is generally good. Two people would find it more logical if all elements are mentioned in every level. Two participants argue that the interrelations of L2 should be implemented in L1 already, and two others argue the same for the assessment of L3.	<p>"The order of implementing the strategy elements seems fitting."</p> <p>"It would be more logical if all five pillars were mentioned in every level, I think that how for example is always present."</p> <p>"The assessment from level 3 should be a part of all levels, performed for the elements discussed in that level."</p> <p>"I understand that this is ambitious, but I consider the interrelations of level 2 so important that I already want them in level 1."</p>
Required for implementation of the strategy	Participants mention that sufficient implementation of the strategy, requires it to be embedded in the project plan and quality handbook. Also the client needs to have a focus on documentation. Participants opt to discuss the concept strategy with entire project team at the start of phase, to determine the feasible level that should be acquired in that project.	<p>"If the strategy would be embedded in the project plan and other standard documents, everyone would automatically know it is important."</p> <p>"The entire team should address all levels and elements and then determine how far to go, followed by already stating plans of actions for the different elements."</p> <p>"If the client asks us for extensive documentation, we provide this but internally we often do not."</p>
Missing elements in the concept strategy	Missing elements are for L0 review rounds as part of documentation activities; for L1 the possibility to connect external documents to a decision; and for L3 a standardization of the required information for pre-design, executive design and definitive design. In general, the participants would like a larger emphasis on the documentation being risk-steered.	<p>"A lot of design decisions are always generated in review rounds."</p> <p>"I miss the possibility to add documents in the environment as support of the design decision."</p> <p>"I notice that the definitions pre-design, executive design and definitive design are very ambiguous, we need to have one standard for that."</p> <p>"Document also the risk that a decision covers."</p> <p>"Risk-steered documentation is what we need."</p>
<i>Current practices</i>		
General comments	All participants agree that in general, these elements are performed in current practices. However, two argue this is mainly for infra- and construction projects and less for the water related projects. All agree that assigning responsibilities is currently performed but not very explicitly.	<p>"This is indeed how we currently work."</p> <p>"I agree this is the level that we have at the moment."</p> <p>"I think these elements are best implemented in the infra sector, for my projects in the water sector it is not done that much."</p> <p>"We do not assign responsibilities this explicitly, but it is clear who is responsible for what tasks."</p>
Perceived bottlenecks for applying this level in practice	Three participants do not mention any bottlenecks for applying this level. The others indicate too little knowledge of Relatics and too much effort in case of small projects as possible difficulties.	<p>"It might not be beneficial for small projects to implement this strategy, as it will take some effort."</p> <p>"Project members might not have the required knowledge of Relatics."</p>
<i>Level 1</i>		
General comments	Participants mention additions for the requirements of documenting a design decision; if the involved costs or risks are high, if it affects requirements and it changes functionality. Generally, they agree that the requirements provide clarity for when documentation is needed. Two participants mention to implement the IPM model of projects more in terms of meetings.	<p>"Maybe add that a design decision should be documented if it leads to high costs or if its risk is high."</p> <p>"A design decision does not only affect other decisions, but also requirements."</p> <p>"The strategy should also mention that a decision should be documented if it changes functionality."</p> <p>"These requirements for documentation are very clear."</p> <p>"Perhaps the IPM model should be considered more explicitly, this strategy mainly focuses on the technical aspect so emphasize this."</p>



**Continuation of Table A.5:** The summarized results of the validation of the concept strategy.

Validation part	Results	Quotes
Perceived bottlenecks for applying this level in practice	It is agreed that the template should be fully equipped at the start of the project, otherwise it would not facilitate the documentation strategy sufficiently. One participant pointed out that designer might perceive the prescribed documentation tasks as administration, especially when obligatory fields are used in the template.	<p>"There should be basic availability of the template, otherwise the strategy will not work."</p> <p>"Everything should be accounted for in the template, this ought to be well facilitated."</p> <p>"Obligatory fields are very useful, but people might really be against using these."</p> <p>"Designers might perceive the documentation as administration, doing it on a separate screen."</p>
<i>Level 2</i>		
General comments	All participants agree that it is beneficial to see visualizations of the design decisions and interrelations in their context. This offers more insight for both the project team and client. They also agree that only the most important interrelations should be documented, and that justification for the relation is not necessary. Three participants suggest that it is very useful if a warning is given if something has been changed that affects your decision.	<p>"The network of interrelations is most interesting for the project team, and the geographical location of the decisions for the client."</p> <p>"Connections are essential if you want to make a complete, structured documentation."</p> <p>"The justification per relation sounds heavy, I think it would be clear without this as well."</p> <p>"The environment should give you a warning if someone changed something that affects you."</p> <p>"The environment should detect clashes between different decisions, based on the relations."</p>
Perceived bottlenecks for applying this level in practice	The elements in this level need a sufficient implementation of SE in the environment to be able to perform satisfactory. Also two people point out that the concept of interrelations might still be hard for some designers.	<p>"If this works is dependent of the level of SE implementation, this might differ from the decomposition of the system on design level and then connections will be incorrect."</p> <p>"You might lose people in the relations."</p> <p>"Maybe connecting design decisions is hard to understand for designers, for them it might be more logical to connect decisions and requirements."</p>
<i>Level 3</i>		
General comments	One participant does not see this as an additional level, but feels that the assessment should be performed at the start of all levels. Another participant suggests that the assessment should be performed by an external party.	<p>"It feels more like a checklist that you use to determine if the strategy levels are implemented correctly."</p> <p>"Should this assessment not be performed by an external person or party?"</p>
Perceived bottlenecks for applying this level in practice	Participants agree that the largest bottleneck for this level is a tight schedule with short-term deadlines. Also, they indicate that is hard to determine beforehand what documentation should be present.	<p>"In practice, you will have to start designing immediately due to time pressure so how would you handle this then?"</p> <p>"It is hard to determine what documentation is required, although this should be possible based on experience."</p>

# NEDERLANDSE SAMENVATTING

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Het documenteren van ontwerpkeuzes heeft een positieve invloed op de traceerbaarheid van deze keuzes en vergroot daarmee ook het inzicht in het ontwikkelingsproces van het project. In de Nederlandse civiele sector wordt Systems Engineering (SE) toegepast in een meerderheid van de projecten ten behoeve van het gestructureerd ontwerpen van complexe systemen. Ondanks het gebruik van SE komen problemen door incomplete of onjuiste documentatie nog vaak voor. Kenmerkend voor civiele projecten zijn de lange doorlooptijd, dynamische natuur en de vele, diverse partijen die betrokken zijn. De vereiste informatieoverdracht tussen zowel verschillende fases als partijen die deze structuur met zich meebrengt, wordt bemoeilijkt bij gebrek aan goede documentatie van ontwerpkeuzes. Daarnaast leidt dit tot heropening van oude discussies en kunnen veranderingen in het project niet eenvoudig doorgevoerd worden.

Dit onderzoek is uitgevoerd in opdracht van een civieltechnisch ingenieursbureau en stelt vast hoe ontwerpkeuzes daar momenteel in de praktijk vastgelegd worden. Daaropvolgend zijn de karakteristieken voor een strategie voor de documentatie van ontwerpkeuzes bepaald. Deze strategie is ontwikkeld voor civiele projecten waarbij SE wordt toegepast.

Allereerst is op basis van een literatuurstudie een theoretisch raamwerk ontwikkeld, die een standaard beschrijft voor de kernelementen van de documentatie van ontwerpkeuzes. Hierna zijn vier weginfrastructuur projecten onderzocht, om vast te stellen hoe diezelfde elementen nu in de praktijk toegepast worden. Data zijn in dit case study onderzoek verzameld door interviews met projectleden en documentenanalyse. De uitkomsten van de literatuurstudie en de case studies zijn met elkaar vergeleken en geanalyseerd door middel van de 'pattern matching' methode. Op basis van deze bevindingen is een concept strategie ontwikkeld, die vervolgens is gevalideerd door verschillende experts. Aangezien in de case studies alleen weginfrastructuur projecten zijn bestudeerd, zijn de participanten van de validatie geselecteerd in andere disciplines van de civiele sector. Uit deze validatie zijn conclusies getrokken en meerdere aanbevelingen voor verder onderzoek gedaan.

De case studies tonen aan dat een groot deel van de elementen van de documentatie van ontwerpkeuzes nog niet toegepast wordt in de praktijk. Een documentatie omgeving die een goede bereikbaarheid van de informatie voor alle betrokken projectpartijen faciliteert wordt momenteel al gebruikt. Ook worden de verantwoordelijkheden ten aanzien van het documenteren van ontwerpkeuzes en het monitoren van deze informatie al verdeeld in de praktijk. Ontwerpkeuzes en de bijbehorende toelichting worden gedeeltelijk vastgelegd, maar aan de documentatie van onderlinge relaties en de context van deze keuzes wordt nog geen aandacht besteed. Het vergroten van het inzicht in de ontwerpkeuzes door middel van visualisaties wordt in beperkte mate toegepast. De documentatie wordt niet onmiddellijk gedaan, voornamelijk omdat een periodieke controle hierop ontbreekt. Ook wordt er in de meeste projecten geen controle van alle overgedragen documentatie gedaan aan het begin van een nieuwe projectfase.

De resultaten van dit onderzoek wijzen verder uit dat de structuur van de strategie, opgebouwd uit vijf documentatie aspecten (wat, wie, wanneer, waar en hoe) goed wordt bevonden. Vanwege de omvang van de strategie is het niet mogelijk om alle elementen als geheel te implementeren, waardoor de strategie is opgedeeld in meerdere levels. Per project dient vooraf bepaald te worden welke levels gehaald moet worden, aangezien het voor sommige projecten niet mogelijk is om de volledige strategie te implementeren door beperkingen in de planning, budget of projectgrootte.