# A data-driven approach for tracking design documents and KPIs in the design phase of infrastructure projects

*Enhancing Situational Awareness through the Design Phase Monitoring Tool (DPMT)*


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Delft University of Technology
Department of Civil Engineering & Geosciences
Master in Construction Management & Engineering


Delft, May 2025

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# Acknowledgements

After completing my HBO bachelor's degree, I decided to delve deeper into advanced Civil Engineering and specialize in Structural Engineering or shift my focus toward the management side of the field. After taking a gap year to reflect, I followed a Master's in Construction Management and Engineering (CME). Following a challenging bridging program, I officially began my studies and adjusted to the more theoretical approach, focusing on courses aligned with my interests. Now, I am completing my Master's in Construction Management and Engineering at Delft University of Technology, with my thesis titled *"A data-driven approach for tracking design documents and KPIs in the design phase of infrastructure projects".* This journey has been far from easy, filled with both smooth and challenging periods. However, like any worthwhile journey, success doesn't come without effort.

Writing this thesis has been a challenging yet rewarding journey, and I could not have completed it without the support of many people. I am genuinely grateful for the guidance, encouragement, and insights I have received throughout this process.

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> *"In preparing for battle, I have always found that plans are useless, but planning is indispensable."*

I hope you enjoy reading my thesis!

*J. (Jeroen) van Schaik*
*Delft, May 2025*

# Executive Summary

The design phase in Dutch infrastructure projects is often delayed due to fragmented data systems and a lack of real-time insight. Companies use multiple platforms, but these are often not integrated. As a result, it becomes difficult to monitor design progress and, therefore milestone progress, responsibilities, and deadlines in a unified way. This lack of situational awareness leads to late issue detection and poor communication. Currently, there is no structured method to track the progress of design documents in combination with Key Performance Indicators.

To address this problem, the research aimed to develop a practical, data-driven solution: the Design Phase Monitoring Tool (DPMT). Built using the Design Science Research Methodology (DSRM), the research followed a structured process involving literature review, interviews with experts, analysis of the current systems and processes at Heijmans, and iterative tool development. The DPMT developed in this research is not merely a visualization dashboard—it represents a structured process-driven approach to managing design activities in complex infrastructure projects. While the proof-of-concept is demonstrated using Power BI, the core value of the DPMT lies in its underlying methodology: defining indicators, structuring data flows, and creating a systematic framework for monitoring progress. This makes the DPMT adaptable across platforms and capable of functioning even when Power BI is not available. As such, the tool should be understood as both a technological artefact and a process innovation that enhances situational awareness and control during the design phase.

The validation of the DPMT through a focus group session revealed several key outcomes. First, it significantly improved visibility by consolidating dispersed data into a single, actionable overview. The users of the tool could, for the first time, see progress in relation to the project schedule, document status distributions, and verification metrics all in one place. Thus enhanced situational awareness allowed teams to act earlier when delays or bottlenecks became apparent. Second, experts within Heijmans responded positively to the tool's potential, expressing that such a dashboard should become a standard part of the design process. Third, the DPMT allowed a shift from reactive to proactive project management, supporting more informed decision-making, and early intervention when risks emerged.

Despite the positive reception, the research also identified areas for improvement. At present, data integration requires manual extraction from core systems, making the process time-consuming. However, this approach can be explained due to the scope of this research. Automating these data flows would allow real-time updated and reduce user effort. Furthermore, the prototype uses static milestone dates, meaning that when schedules change, the dashboard must be updated manually. Users also expressed interest in predictive capabilities. Expanding the tool to address these specific aspects would make it even more valuable for companies to operate in complex, data-rich environments.

In conclusion, this research demonstrates that a structured, data-driven approach to design management is both feasible and beneficial in the design phase of infrastructure projects. The DPMT prototype fills a critical gap by offering a unified overview of progress, tailored to the needs of design managers, design leaders, and project teams. It supports better control over deadlines, improve team coordination, and provides a foundation for further digital innovation, such as predictive analytics. The findings suggest that construction companies should invest in the continued development and integration of such tools, not only to avoid delays but also the raise the standard of design phase performance and project delivery overall.

# Samenvatting


De ontwerpfase van infrastructurele bouwprojecten is complex én cruciaal – hier wordt immers de basis gelegd voor het verdere verloop van het project. In de Nederlandse bouwsector werken ontwerpteams met grote hoeveelheden documenten, eisen en betrokken partijen. Tegelijkertijd is de informatie over die documenten en processen vaak verspreid over verschillende systemen, zoals Relatics voor eisen en M-Files voor documenten. Omdat deze systemen niet met elkaar verbonden zijn, is het lastig om goed zicht te houden op de voortgang. Dit gebrek aan overzicht – ofwel situationeel bewustzijn – zorgt ervoor dat risico's of vertragingen pas laat worden opgemerkt. Er bestaat momenteel geen gestructureerde manier om de voortgang van ontwerpdocumenten en bijbehorende prestatie-indicatoren (KPI's) goed te volgen.

Om dit probleem aan te pakken, is in dit onderzoek een praktische, datagedreven oplossing ontwikkeld: de Design Phase Monitoring Tool (DPMT). Met behulp van de Design Science Research Methodology (DSRM) is een gestructureerde aanpak gevolgd, bestaande uit literatuuronderzoek, interviews met experts, analyse van de huidige systemen en processen bij Heijmans, en een iteratieve ontwikkelfase van de tool. De DPMT is niet zomaar een visualisatiedashboard, maar een gestructureerde, procesgerichte benadering voor het beheersen van ontwerpactiviteiten binnen complexe infrastructurele projecten. Hoewel het proof-of-concept is gebouwd in Power BI, ligt de echte waarde van de DPMT in de onderliggende methodiek: het definiëren van indicatoren, het structureren van gegevensstromen en het opzetten van een systematisch kader voor voortgangsmonitoring. Hierdoor is de DPMT niet gebonden aan één specifiek platform en kan de aanpak ook met andere technologieën worden toegepast. De tool moet dan ook worden gezien als zowel een technologisch hulpmiddel als een procesinnovatie, gericht op het verbeteren van situationeel bewustzijn en het versterken van sturing tijdens de ontwerpfase.

Tijdens een focusgroep met professionals van Heijmans is de tool getest en besproken. De reacties waren positief: voor het eerst hadden ontwerpteams een totaaloverzicht van de voortgang, gekoppeld aan de planning en andere kritieke factoren. Dankzij dit inzicht konden knelpunten eerder worden gesignaleerd en aangepakt. Gebruikers gaven aan dat zo'n dashboard eigenlijk standaard zou moeten zijn bij ontwerptrajecten. Ook werd duidelijk dat de DPMT teams helpt om proactief te werken in plaats van steeds achter de feiten aan te lopen.

Tegelijkertijd kwamen er ook verbeterpunten naar voren. Zo vereist de huidige versie nog handmatige invoer van data uit systemen als Relatics en M-Files, wat tijd kost. In de toekomst zou het dashboard idealiter automatisch gekoppeld zijn aan die systemen voor realtime updates. Daarnaast werkt de tool nu met vaste mijlpaaldata, terwijl planningen in de praktijk vaak wijzigen. Ook gaven gebruikers aan interesse te hebben in voorspellende functies, zoals automatische waarschuwingen bij risico op vertraging. Het uitbreiden van de tool met deze functies – en met informatie over bijvoorbeeld openstaande reviewopmerkingen of interdisciplinaire afstemming – zou de toegevoegde waarde verder vergroten.

Samenvattend laat dit onderzoek zien dat het goed mogelijk is om met een datagedreven aanpak meer grip te krijgen op de ontwerpfase van bouwprojecten. De DPMT biedt een concreet hulpmiddel waarmee teams beter kunnen sturen op voortgang en deadlines. De positieve feedback uit de praktijk onderstreept dat er behoefte is aan dit soort tools. Met verdere ontwikkeling en automatisering kan de DPMT echt het verschil maken in het voorkomen van vertragingen, het verbeteren van samenwerking en het versterken van het gehele ontwerpproces.

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# Nomenclature

| Abbreviation | Definition |
|---|---|
| DDDM | Data-driven design management |
| SO | Sketch Design |
| VO | Preliminary Design |
| DO | Final Design |
| UO | Detailed Design |
| KPI | Key Performance Indicator |
| DSRM | Design Science Research Methodology |
| GWW | Grond-, Weg, en Waterbouw (Dutch civil engineering sector) |
| ACC | Autodesk Construction Cloud |
| DMS | Document Management System |
| WBS | Work Breakdown Structure |
| ML | Machine Learning |
| EWS | Early Warning Signal |
| BIM | Building Information Modelling |
| SA | Situational Awareness |
| WBS | Work Breakdown Structure |
| SBS | System Breakdown Structure |
| AI | Artificial Intelligence |
| OG | Client (Opdrachtgever) |
| OKR | Design Approval Report (Ontwerp Keurings Rapport) |
| VR | Verified Requirements |
| OR | Open Requirements |
| AR | Action Rate |
| WiP | Work in Process |
| BS | Batch Size |
| RW | Rework |
| VFE | Verification Flow Efficiency |
| VD | Verification Delay |
| AVPT | Average Verification Processing Time |
| CDE | Common Data Environment |
| SADT | Structured Analysis and Design Technique |
| ERP | Enterprise Resource Planning (e.g. SAP) |
| API | Application Programming Interface |

# 1
# Introduction

## 1.1. Context

In the last few years, the use of digital technologies has increased across all kind of industries. The construction industry is no exception; it's currently experiencing an intelligent revolution, commonly known as Industry 4.0. This shift has led to a significant increase in data generation (Munawar et al., 2022). However, much of this data remains underutilized. A 2018 FMI report found that 95% of construction data goes unused, with 13% of work hours spent searching for project information and 30% of the companies is using programs that don't integrate with each-other (Snyder et al., 2024). Comparing the construction industry with other industries revealed that the industry is lagging behind. Most problems occur in project performance due to planning, coordinating, and communicating complications relevant to data- and project management. The lack of clear data management approaches is hindering the performance of the industry. This is mainly because the industry heavily relies upon historical data of projects. At the same time, the amount and diversity of data collected from projects is increasing (Wattuhewa et al., 2022). Deloitte's research highlights that while companies collect various data types, only 40% is effectively used for decision-making, with key data like project progress is often neglected (Peccolo, 2023). Maximizing the use of existing data can significantly improve decision-making processes.

Although the literature identifies numerous opportunities presented by digital technologies, their practical implementation during the design phase of construction projects remains limited. As a result, project teams are frequently unaware of emerging bottlenecks until delays have already occurred. Key information—such as the status of design documents, the progress of verification workflows, and the alignment with milestone deadlines—is often dispersed across platforms and not readily accessible in a central location. This fragmentation causes milestone tracking to be reactive rather than proactive. The resulting lack of situational awareness constrains teams' ability to accurately assess ongoing progress, understand its implications, and anticipate risks in time to intervene effectively.

Moreover, the vast amount of data generated throughout the construction process adds to the complexity of project management. Despite the abundance of available information, decisions are often based on intuition or experience rather than on structured, data-driven insights. The ability to process, analyze, and integrate large volumes of data holds significant potential for improving the efficiency, sustainability, and resilience of construction projects (Veras, 2021). However, the main challenge lies in effectively managing and leveraging this data. Many organizations face difficulties in connecting various digital platforms and tools, which leads to fragmented workflows and inefficient data use (McKinsey, 2020).

Recent technological advancements offer new opportunities for project managers to improve decision-making, enhance process efficiency, and increase the likelihood of project success. As Deming and Drucker famously emphasized: *"you can't manage what you can't measure"* (Mcafee and Brynjolfsson, 2012). Yet, defining how to measure success remains a persistent challenge, particularly in complex design environments (Ahadzie et al., 2008). Traditionally, project performance has been evaluated using the Iron Triangle, which balances time, cost, and quality. Managing these three dimensions effectively has long been considered the cornerstone of project success (Atkinson, 1999a; Turner, 1993). However, digitalization has shifted this paradigm. Tools powered by real-time data enable project managers to monitor these dimensions more precisely and even anticipate problems before they escalate (Mergel et al., 2019). Among the most impactful of these are data-driven tools, which not only support more accurate tracking of key performance indicators but also enhance early warning capabilities and enable proactive decision-making (Alihedarloo, 2020).

This lack of integration and limited use of data-driven approaches during the design phase directly reduces what is known as *situational awareness*—the ability of project teams to perceive the current status of the design process, comprehend its implications, and anticipate future delays or disruptions. Originating in domains such as aviation and military operations, the concept of situational awareness is increasingly applicable to complex project environments like infrastructure design (Endsley, 1995). In this context, it refers specifically to the capacity to maintain real-time insight into milestones, document statuses, and verification workflows across disconnected systems.

## 1.2. Problem statement

Despite the increasing emphasis on digital transformation and data-driven tools in the construction industry, the application of these technologies in managing the design phase remains under-explored. Despite the large amounts of data generated across the project lifecycle, from initiating to closing, much of this data remains underutilized. This results in construction companies struggling to integrate it effectively into project management processes. So far, studies indicate that a staggering 95% of construction data is unused, highlighting the industry's lag in adopting digital advancements compared to other sectors (Snyder et al., 2024; Peccolo, 2023). Studies, such as those by Huang et al., (2021), focus predominantly on the execution and monitoring phase of construction, with significant attention paid to data-driven management during those phases. However, there is a lack of research on the integration of data-driven tools during the design phase. As the design phase is critical for defining project objectives, identifying risks, and establishing the foundation for successful execution, the absence of effective data-management strategies at this phase can lead to inefficiencies, delays and cost overruns. Moreover, the complexity of coordinating design tasks, compounded by fragmented data systems, further exacerbates the challenge of milestone management (McKinsey, 2020). The lack of clarity about what data is needed to track milestones effectively results in inefficiencies in design management. Studies also show that fragmented data systems, often used during the design stages, create bottlenecks, making it difficult to track and adjust milestones in real-time (Martinez-Rojas et al., 2016). These challenges collectively contribute to a lack of real-time insight—*situational awareness*—into the design process.

Another gap in current practices is the limited use of production flow concepts in the design phase of construction projects. While industries like product manufacturing have successfully used these models to improve their processes, the construction sector has found it challenging to apply them early in the project lifecycle. Sacks, (2016), points out that managing production flow helps reduce delays and waste during construction. These same principles could also bring similar benefits to the design phase. Using flow-based methods during design could improve milestone tracking and overall project performance.

As a result, the central problem addressed in this research is:

***While the design phase plays a critical role in laying the foundation for a project, delays frequently arise due to a lack of situational awareness, particularly in managing milestones and navigating fragmented data systems. Although data-driven tools are available, there is currently no structured framework that enhances real-time insight and coordination to effectively prevent delays during this phase.***

## 1.3. Research objective

As the volume, speed, and variety of data continue to grow, construction companies are recognizing the need for better control and management of this information. Because of this, all data is treated as a valuable asset, and the delivery of information is often linked to effective project management in literature. Building on insights from the reviewed literature and the identified shortcomings in current practices, this thesis pursues two main goals: first, to identify existing data management practices; and second, to develop a practical data management tool.

The first goal of this research is to identify how design management is currently practiced during the design phase of construction projects, with a specific focus on the Preliminary Design (V0), Final Design (DO), and Detailed Design (UO) stages. This research aims to understand how milestones are defined, tracked, and controlled in each of these stages, and to explore the main challenges that project teams face in meeting critical deadlines. This includes identifying gaps in current methods, limitations in available data, and other factors that contribute to delays during the design process.

The second and main goal of this thesis is to develop a tool that helps construction companies gain better control over the design process. This tool aims to enhance situational awareness by providing real-time insight into the status of design activities, enabling teams to not only perceive current progress but also comprehend its implications and anticipate emerging delays. In doing so, it introduces a structured method for collecting and organizing data—an essential foundation for enabling future applications of advanced technologies such as Artificial Intelligence (AI) and Machine Learning (ML). By first establishing the appropriate data infrastructure, this research lays the foundation for predictive and proactive design management in the infrastructure sector. This means ensuring that the right data is collected in the right format, and that a system is built to support its integration, analysis, and use in decision-making.

In line with the problem statement, the research aims to:

***Develop a tool that enhances situational awareness and supports milestone tracking during the design phase of infrastructure projects.***

## 1.4. Research scope

To keep the research focused and manageable, it is important to clearly define what will be included. This research focuses on the Dutch infrastructure sector, commonly referred to as the GWW sector. This sector involves work such as building levees, bridges, canals, carrying out earthwork, dredging, hydraulic engineering, and road construction. The research will take place at Heijmans' main office in Rosmalen, specifically within the design department of the central projects division. These projects are known for their complexity, which often leads to delays and extended timelines. For this reason, the research will focus on projects valued above 20 million euros. These are classified within Heijmans as risk category three, also called CAT3 projects.

The main objective of this research is to understand and prevent project delays. Although project performance is traditionally measured using the Iron Triangle, which considers time, cost, and quality, this research will focus **exclusively on the time element**. While cost and quality are important, they are indirectly related to time.

This research places specific emphasis on the **design phase of construction projects**. This phase is critical as it forms the basis for everything that follows, from initial concept development to detailed planning. Any delays or issues that arise at this stage can lead to major setbacks later on. These setbacks often include increased costs and schedule overruns, along with potential compromises in the design that may require rework during construction.

The scope will cover three specific stages within the design phase at Heijmans. These are the **Preliminary Design phase**, known in Dutch as Voorontwerp, the **Final Design phase**, or Definitief Ontwerp, and the **Detailed Design phase**, called Uitvoeringsontwerp. During these stages, the design evolves from early concepts into a ready-to-build plan. A detailed schedule will be developed, outlining when each part of the project will be addressed and establishing clear milestones. The goal is to create a design that is integrated, practical, and maintainable, along with a clear plan for execution. This should help ensure that timelines agreed upon with clients and internal stakeholders are met.

The research will also focus on **internal factors** that influence the successful completion of projects. While both internal and external factors can impact performance, this research will concentrate only on those within the organization's control. These include management practices, available resources, and organizational culture. Understanding and improving these factors is key to gaining better control over timelines and avoiding delays.

Although there is growing interest in using Machine Learning techniques to support this kind of work, **developing an actual ML tool is not part of this research**. Creating such a tool would require more time and resources than are currently available. Instead, the aim is to lay a strong foundation that construction companies can build on in the future if they wish to explore and apply Machine Learning technologies.

## 1.5. Research questions

In order to comply with the objective of the research, the main research question must be answered. This answer will follow by answering four sub-questions.

The main research question that must need an answer is:

> *"How can construction companies enhance situational awareness during the design phase by integrating data from multiple systems, to support better milestone monitoring and reduce the risk of delays?"*

Subsequently, this research is guided and structured by four sub-questions:

**Sub-question 1:**

> *"What are the current trends and challenges of data-driven design management in the design phase of projects, and how are milestones currently managed?"*

This question explores the current state-of-art, both in theory and in practice. It investigates how design progress is currently tracked, and what challenges exists. Insights are gathered through a literature review and supported by expert interviews.

**Sub-question 2:**

> *"What can be monitored within the current data-systems, and what are the indicators that create insight into the design progress?"*

Here, the focus shifts to the technical side: what types of information are already being stored in systems, and how this data can be used to monitor design performance. This includes defining relevant indicators that help make the design progress visible and measurable.

**Sub-question 3:**

> *"How can data be structured and managed in the design phase to directly address each indicator and increase situational awareness?"*

This question focuses on the design of the actual monitoring approach. It looks at how to organize and connect data from multiple platforms in a way that supports real-time monitoring and improves clarity for end-users. The insights from previous two sub-questions form the basis for developing the monitoring tool.

**Sub-question 4:**

> *"How can construction companies leverage the tool to enhance control over milestones and reduce the risk of delay?"*

This question addresses the practical application of the tool. It looks at how the developed solution can be used in projects to improve milestone tracking and prevent delays. The answer is informed by a focus group session with experts, aimed at evaluating the tool's usefulness and relevance in practice.

## 1.6. Research methodology

To address the research questions and develop a practical solution, this research follows the Design Science Research Methodology (DSRM). This methodology is well-suited for projects that aim to design and evaluate innovative artefacts grounded in real-world problems. The DSRM provides a structured, step-by-step approach that guides the research through problem identification, artefact development, and evaluation. In this research, the methodology supports the iterative development of a monitoring tool aimed at enhancing situational awareness during the design phase of infrastructure projects. A detailed explanation of the applied methodology, including the selected research methods and design choices, is provided in Chapter 2.

## 1.7. Relevance of the research

This research has practical relevance for professionals involved in infrastructure projects, as it supports more effective design phase monitoring through data-driven methods. Scientifically, it contributes to the growing body of knowledge on Data-Driven Design Management (DDDM) by offering empirical insights and a validated framework for improving milestone tracking and situational awareness.

### 1.7.1. Practical relevance

This research is practically significant as it addresses a core challenge in infrastructure projects: the lack of situational awareness during the design phase. Delays in this phase are often caused by limited visibility into progress, unclear milestone responsibilities, and fragmented data environments. The developed artefact offers a structured, data-driven approach that enhances real-time situational awareness for project teams.

By providing clear insights into milestone status, dependencies, and bottlenecks, the tool enables project managers and designers to act proactively rather than reactively. This improved awareness supports better coordination, reduces the risk of schedule overruns, and enhances decision-making based on reliable and structured data. Additionally, the artefact creates a foundation for future technological integration, such as predictive analytics through Machine Learning or real-time alerts via Artificial Intelligence, further strengthening control and responsiveness in the design process.

### 1.7.2. Scientific relevance

From a scientific perspective, this research contributes to the evolving field of data-driven project management by introducing a structured method to improve situational awareness in the design phase of construction projects. While substantial research exists on project control and data utilization in the execution phase, the design phase remains under-represented—despite its critical role in shaping project outcomes and mitigating early-stage risks.

This research addresses that gap by exploring how data can be used not just for documentation, but as an active component in enhancing understanding, transparency, and coordination during design. The artefact contributes to academic discourse by demonstrating how situational awareness can be operationalized through data-driven tools. It also expands theoretical insights into how construction data flows, which data is most valuable at different decision points, and how early-phase awareness can influence the overall project lifecycle. This research ultimately advances the strategic use of data to support more adaptive and informed design-phase project management.

# 2
# Research Methodology

*This chapter introduces the research methodology. As outlined in Chapter 1, the research adopts the Design Science Research Methodology (DSRM) as proposed by Peffers et al., (2007). Section 2.1 presents the most appropriate research approach for this research. Following the selection of this approach, the chapter details its design, including the specific methods used for data collection and the procedures applied for data analysis.*

## 2.1. Research Approach

A qualitative design approach is adopted to answer the main research question. The research is structured using the Design Science Research Methodology (DSRM) developed by Peffers et al., (2007). This methodology is well-suited for developing practical artefacts and has been applied in projects that involve system design and evaluation in real-world settings.

Design Science (DS) is scientific research aimed at designing artefacts developed and used by people to solve real-world problems. The problem statement is directly linked to the research questions in this context. As described by Wieringa, the design problem research question is the following:

> *"Improve a problem context by (re)designing an artefact that satisfies some requirements to help stakeholders achieve some goals"* (Wieringa, 2014)

The DSRM guides the creation of an artefact. This artefact aims to improve *situational awareness* and monitoring in infrastructure design processes, where data is often fragmented across systems such as Relatics, M-Files, and Autodesk Construction Cloud (ACC).

The research is structured according to the six sequential phases of the DSRM:

A. Problem Identification and Motivation
B. Objective for a Solution
C. Design and Development
D. Demonstration
E. Evaluation
F. Communication

The DSRM provides four potential entry points, enabling the framework to be adapted to specific research needs and contexts. These are:

1. **Problem-Centered Initiation**
2. **Objective-Centered Solution**
3. **Design and Development-Centered Initiation**
4. **Client/Context-Centered Initiation**

This research follows the Problem-Centered Initiation approach, which emphasizes identifying and thoroughly understanding a concrete, real-world problem. This entry point is well-suited for studies addressing known challenges requiring focused and practical solutions. By beginning with a clearly defined problem, the research aims to develop a framework that directly responds to existing inefficiencies within the current context. This approach ensures that the design and development of the artefact remain closely aligned with the practical needs of the organization, thereby increasing the relevance and applicability of the resulting solution. The research structure is outlined in Figure 2.1.

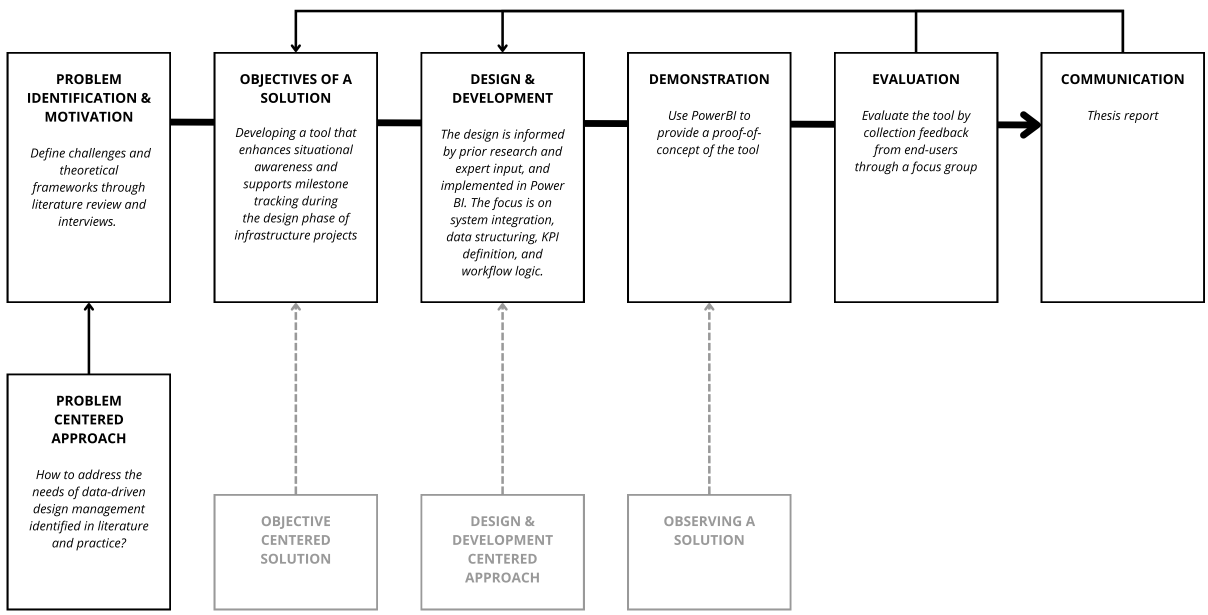



**Figure 2.1:** Design Science Research Methodology

To align with the iterative and practice-based nature of DSRM, a mixed-methods approach is applied, combining qualitative and quantitative data. The qualitative component consists of semi-structured interviews with experts and a case study to uncover context-specific challenges during the design phase. These insights support both the problem formulation and the initial design of the artefact. In parallel, the quantitative component involves analysing project data to identify trends, recurring bottlenecks, and measurable indicators. The combination of qualitative and quantitative methods enables triangulation, enhancing both the validity and reliability of the results. As emphasized by Hevner et al., (2004) and Gregor and Zwikael, (2004), mixed-methods research strengthens DSRM by ensuring that design solutions are both practically relevant and empirically grounded.

## 2.2. Research Design

After selecting the research approach, the next step is to explain how it is applied in practice. The research design is structured according to the six sequential steps defined by Peffers et al., (2007). These steps guide both the structure and execution of the research.

### 2.2.1. Phase A - Problem identification and motivation

The first step was to identify a research problem. Identifying the challenges is essential for gaining a clear understanding of the barriers to effective data-driven design management. For this reason, an intensive literature review focused on data-driven management. This literature review captures various subjects to get a clear view of the research problem. The literature review focuses on different sections:

- Current state-of-the-art, with a focus on data-driven design and situational awareness
- General processes in data-driven design
- Challenges related to data-driven design
- Design development & complexity

Semi-structured interviews with key experts were conducted to complement the findings from the literature review. Semi-structured interviews with design managers and project leaders provided real-world insights, highlighting specific challenges not well-documented in the literature. The interview process is outlined in section 2.3. The interviews focused on the following components:

- Familiarity with the concept of data-driven design management
- Challenges and trends

Together, these methods created a comprehensive foundation for understanding the problem. Phase A will therefore provide the answer to sub-question 1.

### 2.2.2. Phase B - Objective for a solution

This phase defines what the intended solution should achieve. The core objective is to derive monitoring requirements and KPIs that can improve *situational awareness* during the design phase of infrastructure projects.

Three complementary methods were used to formulate this objective: a literature review, expert interviews, and a case study. Together, these methods provided both theoretical grounding and practical relevance. Based on initial findings, the objective of the solution was defined as:

> *Developing a tool that enhances situational awareness and supports milestone tracking during the design phase of infrastructure projects.*

The three methods applied in this phase all served to provide a clearer overview of what the intended solution should achieve:

**The literature review focused on:**

- Measuring performance in the design phase
- Defining and applying relevant KPIs
- Information flow in data-driven design management

**The semi-structured interviews focused on:**
*The semi-structured interview specification is outlined in section 2.3*

- Current practices in milestone management
- Factors contributing to design delays
- The perceived value and use of KPIs in practice

**The case study focused on:**
*The case-study specification is outlined in section 2.3*

- The use of digital systems, verification processes, and milestone tracking in real projects
- Identifying bottlenecks and inefficiencies in workflow execution
- Opportunities to improve visibility and control within the design process

These steps helped build a detailed understanding of current workflows and exposed key opportunities for improvement. This phase followed an iterative approach: as more empirical data was collected and analysed, the problem definition was refined, and the objectives of the solution were continuously adjusted to align with both theoretical insights and the practical needs of the case context. Phase B will therefore provide the answer to sub-question 2.

### 2.2.3. Phase C - Design and Development

This phase focuses on the design and technical development of the DPMT. The DPMT aims to enhance insight and control during the design phase by integrating data from existing systems, such as M-Files, Relatics, and Autodesk Construction Cloud (ACC), and visualizing progress through defined KPIs. The methodological approach taken in this phase is grounded in insights from literature, interviews, and the case study, all of which informed the technical and functional design decisions. The tool was developed in Power BI and was selected for its compatibility with data connectors, intuitive interface, and accessibility for end users. The rationale behind this platform choice is further elaborated in section 7.1.1. Phase C contributes directly to answering sub-question 3 of this research.

The development process followed a structured and iterative methodology. It began by translating the needs identified in earlier phases into concrete requirements. These were shaped by input from the literature review, insights from expert interviews, and case study observations. Together, these sources defined the core functions the tool should support to address the challenges identified in current design management practices.

Another key part of this phase involved defining the KPIs that would be used to monitor performance and progress during the design process. These indicators were selected based on performance measurement indicators found in the literature and practice. Their selection aimed to provide actionable insight while remaining realistic in terms of data availability.

Once the requirements and KPIs were outlined, a system architecture was designed to define how the tool would process and connect data across platforms. This architecture emphasized modularity and flexibility to ensure that future extensions or adaptations would be feasible without significant structural changes.

The entire development followed an iterative approach. Initial tool concepts were translated into functional Power BI prototypes and evaluated in relation to the research objectives. Each iteration led to further reflection and adjustment, ensuring that the design remained aligned with both theoretical requirements and practical challenges. Through this iterative process, the DPMT design was shaped into a solution that supports enhanced situational awareness in infrastructure design management.

### 2.2.4. Phase D - Demonstration

In this phase, the DPMT is demonstrated as a *proof-of-concept*, using actual project data within Power BI. This form of demonstration aligns with the principles of the DSRM, where a proof-of-concept is considered a valid and practical way to illustrate the utility of an artefact. It provides tangible evidence of how the tool addresses the identified problem, even when applied in a controlled or limited project setting (Hevner et al., 2004; Johannesson & Perjons, 2014; Peffers et al., 2007).

Specifically, the DPMT is applied to show how it enhances design tracking, facilitates the visualization of relevant KPIs, and improves overall transparency throughout the design process. This demonstration lets stakeholders understand progress across various design stages (VO, DO, UO), including document verification and requirement completion.

The proof-of-concept emphasizes the tool's capability to function in a fragmented, multi-system environment, bringing together siloed data into a unified monitoring dashboard. By bridging these information gaps, the DPMT supports proactive decision-making and improves situational awareness. As such, this demonstration serves as a critical step in validating the tool's practical relevance and feasibility, in line with DSRM's fourth phase: demonstration.

### 2.2.5. Phase E - Evaluation

A structured focus group is included as part of the evaluation strategy to assess the design decisions and practical relevance of the artefact. The session is conducted with design managers and design leaders. A step-by-step PowerPoint presentation is used to structure the evaluation. This presentation walks participants through the initial problem framing, the research methodology, the logic behind indicator selection, and finally, the proof-of-concept of the DPMT. This format ensures that participants evaluate the artefact in a systematic way without being influenced by outcomes or results.

Focus groups are widely recognized in design science research as an appropriate method for evaluating artefacts, especially during formative stages. They offer a structured yet flexible environment in which experts can assess the utility, relevance, and usability of a proof-of-concept, while also providing valuable feedback for further refinement (Hevner et al., 2004; Peffers et al., 2007; Venable et al., 2012).

The evaluation is intended to determine whether the developed artefact aligns with stakeholder expectations, supports monitoring needs, and can be feasibly applied in practice. Attention is also given to collecting suggestions for improvement and validating the artefact's utility in enhancing situational awareness. The focus group outline is given in section 2.3.

### 2.2.6. Phase F - Communication

Although part of Peffers' original DSRM framework, this research excludes the communication phase, which focuses on disseminating the artefact to a broader academic or professional audience. As the scope of this research is limited to the tool's design, demonstration, and evaluation, broader communication and adoption are considered outside the thesis scope. The outcomes of the research will only be presented in this thesis report.

## 2.3. Evaluation and Justification of Research Method

Section 2.2 outlined the steps followed in each phase of the DSRM. This section explains the specific research methods used, namely the case study, interviews, and focus group.

### 2.3.1. Case-study

Guided by the research questions, a case study will be conducted to gather more practical insight. This approach provides a structured way to analyse and improve situational awareness in the design phase. A completed project from Heijmans' portfolio was selected to examine the current state of practice. This analysis focuses on addressing the first two phases of the DSRM. The completed project was chosen due to the availability of project data, including document submissions, milestones, and information from the systems in use. These data allow for a comprehensive understanding of the existing processes and identifying inefficiencies. Based on the insights gained from phases A and B, an artefact will be developed to address the identified challenges. To ensure the case study is comprehensive and aligns with the research objectives, the following criteria apply:

1. It must involve using data systems such as Relatics, M-Files/DMS, Autodesk Construction Cloud (ACC), or similar platforms for tracking project data and milestones.
2. The project should have sufficient complexity, involving multiple disciplines or teams
3. It should be a CAT3 project
4. The project's design process is finished or almost finished

### 2.3.2. Semi-structured interviews

Interviews are used to help answer a central research question. There are two main types: structured and unstructured. In a structured interview, all the questions are prepared in advance, asked in a fixed order, and usually have set answer options. In contrast, unstructured interviews are more flexible. There are no fixed questions or order, and no predefined answers.

The choice between these types depends on the kind of research question. A closed question usually fits a structured interview, while an open question works better with an unstructured format. Since this research is based on the open question *"How can construction companies enhance situational awareness during the design phase by integrating data from multiple systems, to support better milestone monitoring and reduce the risk of delays?"*, a flexible approach is more suitable.

There are different levels of structure within unstructured interviews. This research uses a semi-structured interview format. This means that the main topics are prepared based on the literature review, but the interviewer can ask follow-up questions during the conversation. This helps explore new ideas and insights that might not have come up otherwise, making it a good fit for this kind of research.

**Table 2.1:** Comparison of interview types

| Free-attitude interview | Semi-structured interview | Partly-structured interview |
|---|---|---|
| No fixed topics, no fixed order | Topic list, no fixed order | Fixed questions and order, but possibility to ask follow-up questions |

**Interview selection criteria**

For the interviews, selection criteria were defined to ensure that participants have relevant knowledge and experience related to the research topic.

- Active involvement in Dutch Infrastructure projects and variations in projects;
- Experience of at least 5 years;
- Position in the company as design manager or design leader;
- Does have experience with CAT3 projects within Heijmans.

**Reliability of the semi-structured interview**

Ensuring the reliability of data collection methods is crucial for the credibility of the findings. Semi-structured interviews are particularly sensitive to issues of consistency and interpretative bias. Reliability in this case refers to the extent to which interview responses are free from coincidence or random variation (Baarda et al., 2012). Given the open-ended nature of this type of interview, differences in interviewer behaviour or question phrasing can influence outcomes. Therefore, George (2022) indicated measures to ensure the reliability of the semi-structured interviews.

- *Interview protocols should be standardized:* Semi-structured interviews were conducted using the interview protocol provided in Appendix A. Since all participants are native Dutch speakers, the interviews were held in Dutch. To ensure transparency and accessibility, the protocol's Dutch and English versions are included in the appendix. The protocol begins with a short introduction explaining the purpose of the interview and the central research question. This is followed by the main section, which starts with general questions about the interviewee before transitioning into more specific topics. Each topic is introduced with a broad, neutral question to avoid steering the responses. The topics were developed based on insights from the literature review and together form the interview's topic list. The interview ends with a word of thanks, an opportunity for the interviewee to ask questions, and a check to see whether they would like to receive the research results. (Baarda et al., 2012).
- *Pilot test of interview protocol:* A 'test' interview was used to evaluate the protocol for redundant or missing topics, clarity of the structure and formulation, and whether there is enough information for the interviewee to respond to the topics. The 'test' interview was held with a central project design team leader within Heijmans.
- *Documentation of the interview:* Audio recordings of the interviews will be used to increase the reliability of the interview transcripts used for the analysis. All interviewees have been informed through an informed consent document. Furthermore, a risk assessment and mitigation plan have been made to perform research involving human participants. The data generated during the research is stored according to the data management plan. The informed consent document, the risk assessment, the mitigation plan, and the data management plan have all been approved by the Human Research Ethics Commission (HREC) of the Technical University of Delft.

**Validity of the semi-structured interviews**
The validity of the interview results refers to the extent to which the collected information accurately reflects actual practices in the field Baarda et al. (2012) as well as the degree to which the findings can be considered reliable and trustworthy (George, 2022). According to George, several strategies can be employed to enhance the credibility and overall quality of semi-structured interview outcomes.

- *Determine relevant topics:* The content of the interview protocol is partly based on the literature review and partly on investigating the current inefficiency, needs, and requirements.
- *Develop a structured interview:* All interviews are conducted based on the same interview protocol
- *Use a diverse sample:* A total of 11 interviews were conducted, with the interviewees selected in consultation with Heijmans. The participants include individuals in the following roles: senior design manager, design manager, design leader, integral design leader, and risk officer. See table 2.2
- *Neutral Environment:* The goal was to interview each participant at the main office in Rosmalen. Ultimately, two of the 11 interviews were conducted via MS Teams, and one was at the project location.
- *Documentation of the interview:* Each interview was recorded, and the audio recordings were used to enhance the reliability of the transcripts.

**Table 2.2:** Overview of interviewees and their experience

| Interviewee | Position | Role[1] | Job Experience | Project focus | Affinity with |
|---|---|---|---|---|---|
| X1 | Contractor | DL, IDL | 4 years | Water infrastructure | Integral projects |
| X2 | Contractor | SDM | 20 years | Large integral projects | Digital building |
| X3 | Contractor | DM | 1 year | Integral projects | Design management |
| X4 | Contractor | SDM, RO | 10 years | Diverse set of projects | Risk office |
| X5 | Contractor | DL | 13 years | Large infrastructure | Process knowledge |
| X6 | Contractor | SDM | 10 years | Large infrastructure | Process development |
| X7 | Contractor | DL | 7 years | Energy transition | Process & data |
| X8 | Contractor | DL | 17 years | Schiphol Airport | Large projects |
| X9 | Contractor | DM | 10 years | Regional projects | Smaller projects |
| X10 | Contractor | DL | 13 years | Road design | Innovation |
| X11 | Contractor | DL | 15 years | Lock projects | Multidisciplinary projects |

### 2.3.3. Data analysis

Effective data management and analysis are crucial when working with interview data, especially since the open-ended nature of semi-structured interviews makes responses less directly comparable than in structured formats. The analysis of the interviews in this research aimed to achieve three main objectives: (1) to gain insight into how milestones are currently managed in practice, (2) to find the current challenges and inefficiencies, (3) to explore whether any indicators are used to monitor the design process, and if so, which ones, and (4) to identify KPIs that can be used to track progress during the design phase.

**Approach**

The data analysis approach follows a series of structured steps. The analysis was conducted using the software Atlas.ti 2025 ("Atlas.ti", 2025), which facilitates the systematic organization and examination of the data. The steps followed in the analysis are outlined below. Figure 2.2 provides a clear overview of these steps, highlighting the distinction between the deductive and inductive coding approaches.

1. Transcribe the audio recordings of the interviews
2. Import the transcripts into Atlas.ti 2025
3. Create codes that capture the meaning of each text segment
4. Create categories of codes based on the topics of the interview protocol
5. Revise codes throughout the coding process because, due to the repetition of all interview transcripts, codes may become too broad and need sub-codes
6. Create groups of codes to identify patterns and connections between different or within topics
7. Interpret the results based on the groups of codes and search for parallels and discrepancies between the interviewees' statements
8. Process the analysis findings by clearly indicating what each interviewee of a group of interviewees states

The analysis process started by developing a set of central themes in Atlas.ti, guided by the research questions. A deductive coding approach was used initially, where codes were applied to relevant sections of the interview transcripts based on predefined categories drawn from the research questions and key concepts from the literature review. Each text segment was systematically coded and linked to one of the main themes. An inductive coding approach was also integrated to remain open to new insights. This allowed for discovering unexpected patterns or themes emerging directly from the data. After the initial coding round, overlapping codes were merged, and subthemes were introduced within each central theme. This iterative process helped refine the coding structure to ensure that themes and subthemes accurately reflected the interview content while staying aligned with the research's objectives.

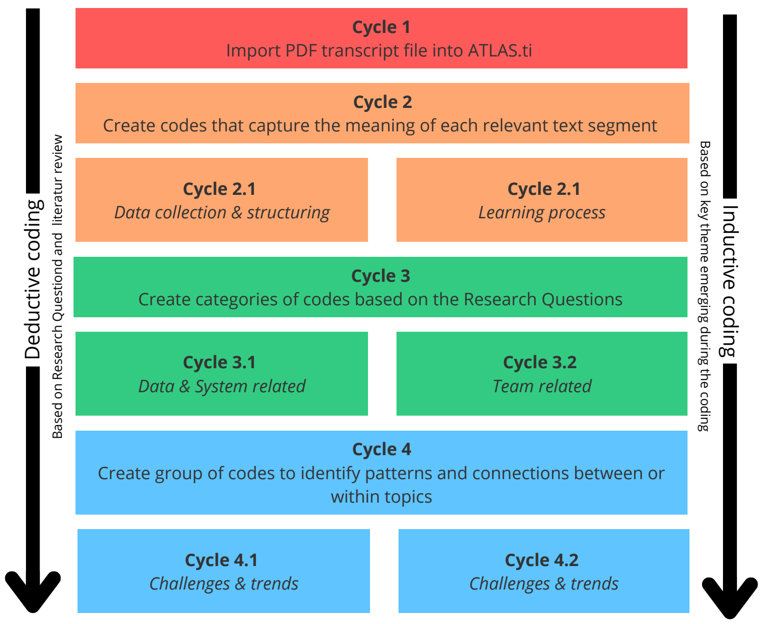



**Figure 2.2:** approach to deductive and inductive coding using Atlas.ti

[1]DM = Design Manager, DL = Design Leader, IDL = Integral Design Leader, SDM = Senior Design Manager, RO = Risk Officer

Table 2.3 presents an example of the coding process used to analyse interview data. Text segments are assigned codes that capture their meaning, categorized based on the research questions, and grouped into overarching themes. For example, X1 addresses data collection challenges, classified as "Challenges & Trends" and grouped under "Data & System related." This structured approach identifies key themes and ensures the research's objectives are aligned. The table demonstrates how data is systematically organized for thematic analysis.

**Table 2.3:** Example of coded text segments, their associated categories, and grouped codes for analysis.

| | **Example of text segment** | **Codes capturing meaning of each text segment** | **Create categories of codes based on Research Questions** | **Create groups of codes for analysis** |
|---|---|---|---|---|
| X1 | And I think especially that the final step, actually using that data, recording it in a structured way, is not yet something... We're not really doing that in a structured manner yet. | Data collection & structuring | Challenges & Trends | Data & System related |
| X3 | So, ultimately, this becomes the same for every discipline. Every week, you discuss progress with the different disciplines and the challenges they face, so you stay focused and can continuously steer to ensure the milestone is achieved. But this is all based on the conversations you have. It is *not made visual.* | Lack of visual data, Design meeting | | |
| X1 | The system also evolves. So, we might eventually switch to a different application. You've already heard about various planning applications, different document management systems you've encountered, and different versions of Relatics. | Different versions & applications | | |
| X7 | Yes, as I mentioned, I sit down with the lead engineer each week. I ask them if their documents are ready and if they can show progress on activities. Is your calculation finished? Yes or no? | Activity based tracking | Indicators to check progress | Data Management |
| X9 | It's a great system for organization. With Relatics, which I've become quite familiar with, you could utilize it much better, even for tasks like document management or document review, for example, which we currently don't do in Relatics. | Relatics, Document based tracking | | |
| X11 | Well, what would help me is simply having an overview of the progress of the design in terms of where we stand with the requirements, where we stand with the interfaces, and where we stand with the risks. I would like to see that at a glance. | Number of requirements, Number of interfaces, Risks | | |

**Relevance of identified KPIs**

To ensure the delay factors and KPIs identified in the interviews were reliable and relevant, a follow-up check was conducted with the same experts who participated in the interviews. This step was meant to see whether the findings made sense to them in practice and whether they actually helped them understand the design process and track progress.

After reviewing the interview transcripts, a list of common delay factors and KPIs was compiled based on recurring themes and expert input. A short follow-up questionnaire was sent out via Google Forms to all interviewees to refine this list. They were asked to review each item and share their thoughts on:

- Whether the factor provides no insight, limited insight, or significant insight into the design tracking process.
- Whether any factors or KPIs were missing and should be included.

An importance index was calculated using the responses from the Google Form to get a clearer picture of which indicators mattered most. This made it easier to rank the indicators and see which were most helpful for tracking progress during the design phase. The form also allowed participants to leave comments or suggestions, adding valuable context to the scores. Combining this ranking with expert feedback made it possible to focus only on the truly relevant and useful KPIs. This helped lay the foundation for a practical and well-supported measurement approach.

### 2.3.4. Focus group

A focus group discussion is conducted with key stakeholders within Heijmans to validate the artifact developed in this thesis. The primary objective of this validation process is to assess the artifact's feasibility, practicality, and applicability. The focus group is held with six design managers and design leaders within Heijmans. The session followed a structured approach using a step-by-step PowerPoint presentation. This presentation outlined the research process and the rationale leading to the development of the artefact, ensuring a logical build-up toward its demonstration. This format helped participants understand the artefact's context, objectives, and intended use, facilitating meaningful and well-informed feedback.

**Participant criteria**
The focus group will comprise design managers and design leaders from Heijmans, ensuring that all participants have extensive experience managing and overseeing design processes. The selection The criteria for participation include:

- A minimum of 5 years of experience in design management within Heijmans or other construction companies
- Direct involvement in planning and tracking within the design phase
- Familiarity with data-driven tools and methodologies used for managing design processes

**Focus group set-up**
The focus group session will be structured to encourage open discussion while maintaining a clear agenda to address all relevant aspects of the artefact. The setup includes:

- **Session duration:** The discussion will last approximately 90 minutes
- **Facilitator:** The session will be facilitated by the researcher to ensure consistency and focus in the discussion
- **Format:** The session will be semi-structured, with predefined discussion points while allowing room for open-ended feedback. The discussion is organized around a step-by-step PowerPoint presentation. First, the overall research goal is introduced, including results from the interviews and case study. After the development process of the artefact is explained, the artefact is demonstrated.
- **Location:** The session will be conducted physically at Heijmans' main office in Rosmalen.
- **Recording and documentation:** The session will be recorded and transcribed for analysis.

**Discussion points**
The focus group discussion will cover the following key areas:

1. The relevance of the identified indicators related to tracking the progress of the design phase
2. The clarity and usability of the proposed artefact
3. Data and interpretation possibilities
4. The feasibility of integrating the framework into Heijmans' existing workflows
5. Potential barriers to implementation and recommendations for improvement
6. Expected impact of the artefact on the design phase

### 2.3.5. Time horizon

This research is part of a graduation project, so the available time is limited. Ideally, the artefact would undergo multiple testing cycles, evaluation, and refinement to ensure continuous improvement and alignment with real-world needs. However, within the scope of this research, the artefact will be evaluated in a single validation cycle using a focus group of experts. The focus group consists of experts who previously participated in the interviews, allowing for a structured discussion on the artefacts' applicability, strengths, and areas for improvement.

## 2.4. Research structure

The overall structure of this thesis follows six sequential phases, aligned with the Design Science Research Methodology (DSRM) by Peffers et al. (2007).

Phase A begins in Chapter 3, which presents a literature review on data-driven design, key challenges in the design phase, and the role of milestone tracking. These theoretical insights are expanded upon in Chapter 4, which presents the results of expert interviews conducted within Heijmans. Together, these chapters refine the problem statement introduced in Chapter 1 and conclude Phase A by identifying the practical and theoretical challenges that justify the development of a monitoring solution.

Phase B is addressed in Chapters 5 and 6. Chapter 5 outlines the monitoring needs from both literature and practice, identifies relevant KPIs, and defines the functional requirements and objectives that guide the development of the artefact. Chapter 6 analyses the current practices within Heijams. Phase C is covered in Chapter 7, which presents the construction of the DPMT. This includes the outline of the artefact, the derivation of design requirements and indicators, the operationalization of KPIs, and the development of the system architecture using Power BI and project data from existing digital tools.

Phase D is presented in Chapter 8, where the DPMT is demonstrated as proof-of-concept using project data. This demonstration illustrates how the tool functions in practice, visualizes milestone status and KPIs, and enables improved design phase monitoring. Phase E is conducted in Chapter 9 through a focus group session with Heijmans practitioners. This session assesses the tool's practical relevance, usability, and completeness. Chapter 10 concludes the thesis by discussing the results in light of the literature, reflecting on the research's scientific and practical relevance, and outlining limitations and future research directions. The conclusions and recommendations are presented in Chapter 11. The research concludes in phase F, which is this thesis report.

A visual summary of the whole research design is provided in Figure 2.3.

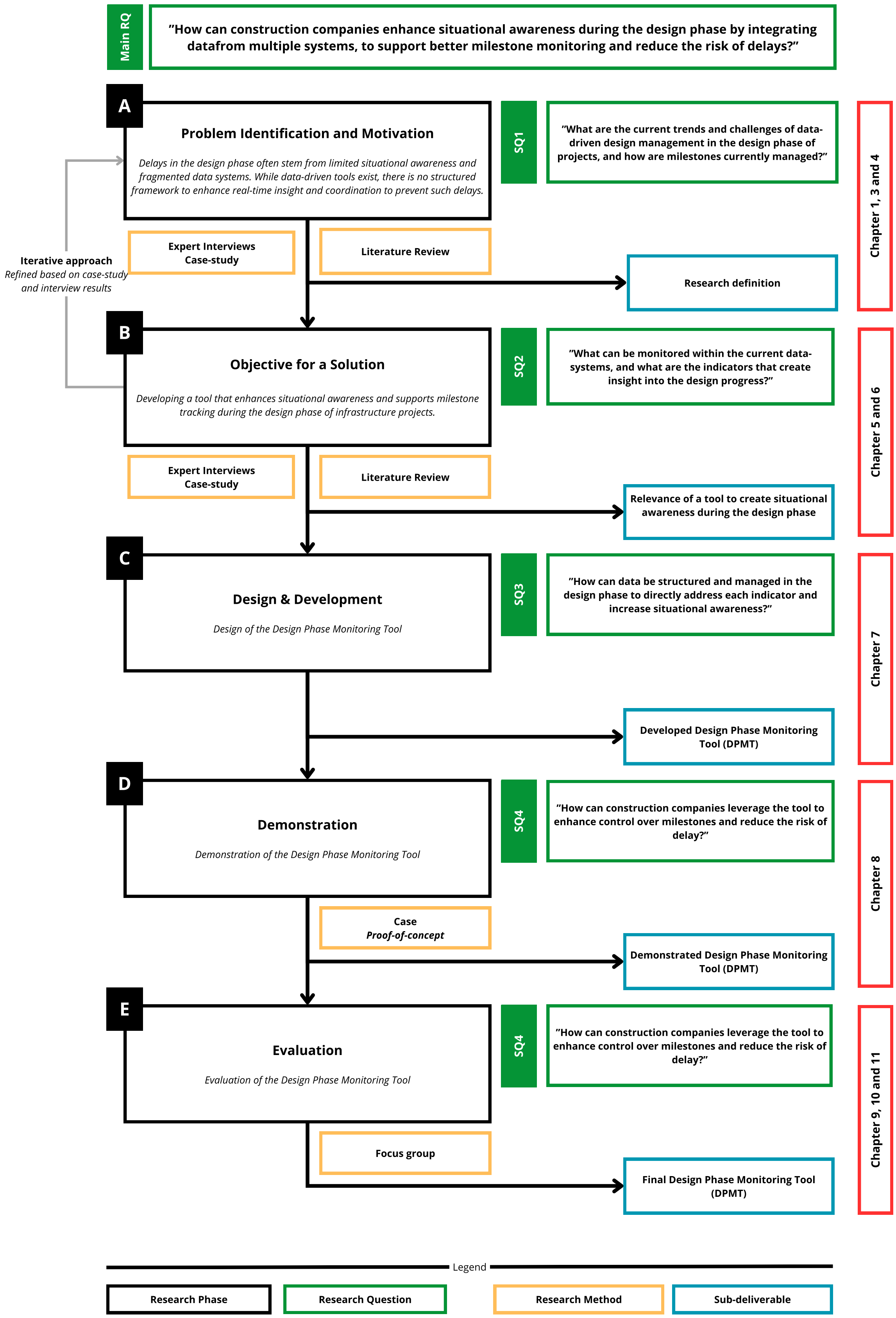



**Figure 2.3:** Research structure

# Phase A

## Problem Identification and Motivation

# 3

# Literature review

*Phase A begins by laying out the* ***scientific foundation*** *of the research, exploring relevant literature to understand the key concepts and challenges associated with data-driven design management. This section focuses on theoretical insights, including milestone tracking, production flow concepts, and the role of data-driven tools in improving design phase processes.*

## 3.1. Current state-of-art

A key question today is how design practices will evolve in the future. This is significant because it influence many of the activities currently shaping the industry. Over the past few years, companies in a variety of domains, have started adopting data driven design practices. A search for ”data-driven design” on SCOPUS (accessed Oct. 16, 2024) resulted in 1279 publications. A quick review showed that the term is being used in a wide variety of fields, including engineering, computer science, design, civil engineering, controls, etc. Since 2016, the number of papers on ”data-driven design” has increased significantly (Bertoni, 2020). The literature on DDD can often feel overwhelming because it spans across multiple disciplines and research fields, each using its own terminology. This makes it difficult to follow, as the concepts and terms can vary depending on the source. As a result, it is still difficult to find a common definition of the term DDD.

### 3.1.1. Data-driven design

The knowledge generated and stored during the design process can play a crucial role in supporting current and future design phases. A knowledge platform enables the reuse of insights from previous designs, enriching the database with each completed project. Such a platform requires three key components: project data, an effective storage method, and a mechanism for extracting valuable information out of this platform (Hofstee, 2018).

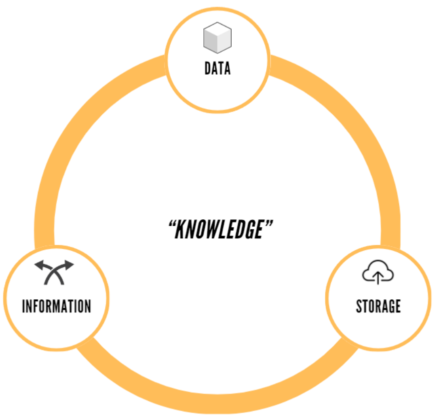



**Figure 3.1:** The three components data, storage and feedback to create a knowledge platform (Hofstee, 2018)

A knowledge platform can serve as a critical tool for supporting data-driven design. Using the definition provided by Patil (2011), data driven design is *the ability of a company to acquire, process, and leverage data in order to create efficiencies, iterate and develop new products, and navigating the competitive landscape.* Trauer et al. (2020) define data-driven design (DDD) as *"a framework for product development in which the goal-oriented collection and use of sufficiently connected product life-cycle data guides and drives decisions and applications in the product development process"*. Following Cantamessa et al. (2020), the term "data" can be defined more broadly and divided into two categories. "Demand-side" data includes data from potential and actual customers. "Supply-side" data includes data generated by the company itself, eg., collection from systems and inputs and outputs from previous designs.

Data-driven design represents a shift from traditional approaches, where development is primarily guided by predefined requirements, to a model where continuous data collection informs development throughout the system's life-cycle. With advancements in data capabilities, this information can be leveraged to extract valuable insights and knowledge (Kim et al., 2017). By incorporating data collection, processing, and utilization into the design process, there is potential to enhance and optimize design outcomes. In this context, the concept of data-driven design (DDD) has emerged in recent years (Kim et al., 2017), describing a decision-making approach in the design process that is grounded in prior data gathering and analysis (Gerschütz et al., 2021; Holmström Olsson et al., 2019).

Based on this research, the following definition for data-driven design will be used for this research:

> *Data-driven design in construction is* ***the ability*** *of a company to acquire, process, and leverage systematically collected "supply-side" data* ***to guide decision-making*** *throughout the design phase* ***to improve project outcomes***

### 3.1.2. Situational awareness

This definition of DDDM is closely aligned with the concept of *Situational Awareness* (SA). The term originates from cognitive psychology and human factors research, particularly in the context of aviation and military operations, where real-time decision-making is critical. The most cited and foundational definition comes from Endsley (1995), who defines SA as:

> *"The perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."*

Endsley's model breaks SA into three hierarchical levels:

- **Perception** – the detection of critical elements in the environment.
- **Comprehension** – understanding how these elements relate to project goals.
- **Projection** – anticipating future states and risks.

In project environments like construction, situational awareness is not just about seeing data, but about integrating, interpreting, and using it to make proactive decisions. It is especially relevant in data-rich, time-sensitive contexts like the design phase, where fragmented information across platforms such as M-Files, Relatics, and ACC impairs team coordination and decision-making.

Several studies have expanded the SA concept into project management and design coordination, emphasizing that low situational awareness leads to:

- Missed deadlines due to late detection of progress issues,
- Delayed responses to emerging risks or design conflicts,
- Ineffective communication and rework due to siloed information.

As highlighted by Salmon et al. (2008) and Chiocchio et al. (2011), situational awareness plays a critical role in collaborative, data-driven settings. In these environments, SA is not an individual attribute alone but a shared, systemic capability among team members.

## 3.2. General process in data-driven design

Data-driven design is seen as a ”true paradigm shift” that is expected to transform design practices (Cantamessa et al., 2020). While much of the existing literature on DDD focuses on product development, the challenges and trends identified can be equally applied to other sectors, such as the construction industry, where similar opportunities for innovating exist. In engineering, data-driven models are applied both for predictive purposes, such as forecasting the future value of a variable, and for descriptive objectives, such as uncovering patterns and gaining insights from existing data. These models leverage available data to improve decision-making by identifying trends and relationships that inform both future outcomes and the underlying structure of the system (Anand and Büchner, 1998).

It's essential to consider how data is used and who or what is responsible for making decisions based on it. While the earlier definition of Trauer et al. (2020) focuses on data to support human decision-making in design, some interpretations suggest that ”data-driven” decision-making is fully automated by machines (Verganti et al., 2020; Pryszlak, 2019). Research by Stewart (2019) and Aishah (2020) made a distinction between ”data-driven”, ”data-inspired”, and ”data-informed”. A data-driven approach involves decisions that are fully automated, with machines processing the data and making choices based solely on that input. In contrast, a data-inspired method uses data as a source of insight and exploration, but human creativity still plays the leading role in decision-making. Lastly, in a data-informed approach, humans make decisions with the support of analyzed data, allowing data to guide but not entirely dictate the outcome. A picture view of the data-driven design process is provided in figure 3.2.

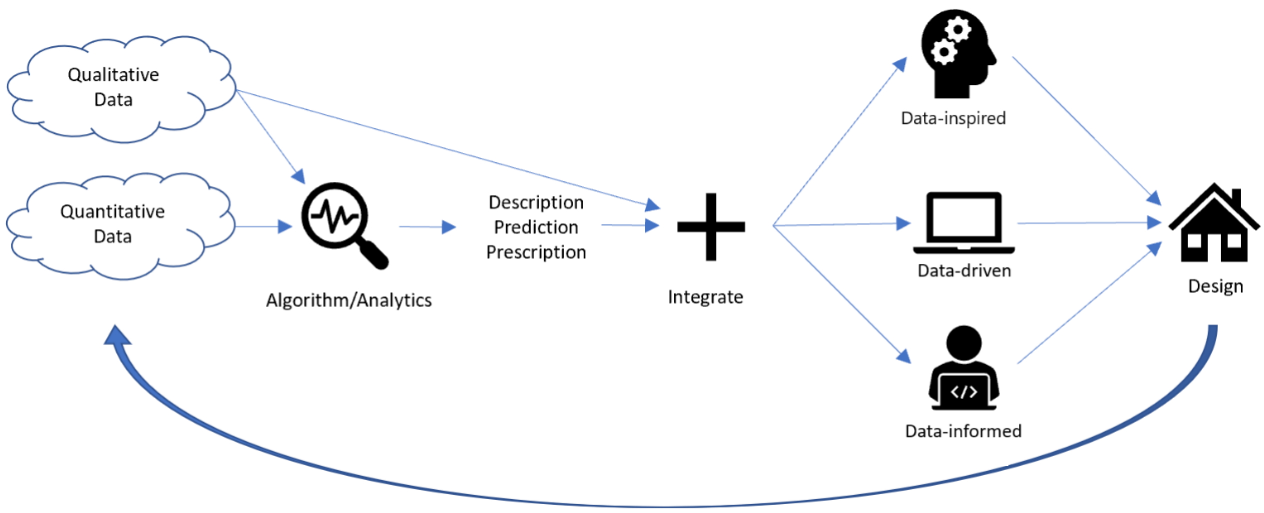



**Figure 3.2:** Data processing in data-driven design. Johnson et al. (2023)

In complex environments, such as large-scale infrastructure projects, decision-makers can use two distinct types of models to support decisions. First, *substantive models* focus on capturing the priorities and criteria directly related to the real-world situation. These models represent key aspects of reality that are important for the decision at hand, such as cost, resources, or timelines in a project. They provide an objective framework to evaluate alternatives based on factual information. On the other hand *preferential model* are designed to facilitate discussions among decision-makers by incorporating their preferences and values. These models help evaluate different alternatives based on subjective criteria (Wierzbicki et al., 2000). Additionally, research shows that in large-scale projects, individual intuition plays an important role in the decision-making process (Flanagan et al., 2007). building on the tacit knowledge and experience of the people working within the company. In the context of new project processes, the complexity and rapid evolution of information make it unlikely that quick, intuitive decisions will consistently outperform well-prepared, analytical ones. Consequently, the value of using computerized systems to support decision-making is widely recognized and undisputed, as these tools help manage intricate and dynamic information more effectively than intuition alone.

## 3.3. Challenges related to data-driven design (DDD)

However, integrating data-driven design models to support decision-making during the design phase presents several challenges. Despite the growing availability of data, effectively utilizing it in design processes continues to pose a considerable challenge for practitioners (Zhan et al., 2018).

First, while companies typically have vast amounts of data that could support decision-making (Wu et al., 2013), they often lack visibility into the data already stored within their systems and the new data being generated. This limited awareness restricts their ability to harness this data effectively for design-related decisions (Altavilla et al., 2017; Arnarsson et al., 2018). Secondly, even when data is accessible, designers frequently struggle with how to fully leverage it in the decision-making process. This gap in utilizing available data optimally can hinder innovation and efficiency during the design phase (Arnarsson et al., 2018). Thirdly, each expert interprets the data based on their specific technical background or role, leading to varied opinions on what criteria are most relevant and which data should be collected and analyzed. The challenge lies in ensuring that decision-making models account for these differing interpretations and do not assume a uniform understanding among experts. For a framework to be effective, it must not function as a "black box." Instead, it should be transparent and understandable, allowing all experts to grasp how the data are prioritized and used (Bertoni, 2018).

Fourthly, In design stages, decisions can or must be made with incomplete information. A framework need to balance between including enough data to support decisions and ensuring that data is manageable without giving a false sense of precision. In other words, the model should help designers make informed decisions, even when the available data is incomplete (Bertoni, 2018). Fifthly, during design, the data available may be both numerical and nominal. A good framework should be able to handle both types of data simultaneously to give a full picture of the design (Bertoni, 2018), and at last, humans have a limited capacity to process large amounts of complex information, especially under time pressure. A framework should represent data in a way that makes it easy for designers to understand and use, helping them to see patterns and relationships without getting overwhelmed by too much detail (Bertoni, 2018).

In addition to those challenges. Lohman et al., (2003) identified four primary bottlenecks that impact the effectiveness of management information and therefore can have impact on data-driven design. The first bottleneck, *data availability and quality*, underscores that effective management information depends on reliable data. However, data in organizations is often incomplete, inaccurate, or outdated, leading to flawed decision-making when these issues go unaddressed.

The second bottleneck, *mismatch between requested and provided information*, occurs when the data given to managers does not align with their actual needs. This misalignment, often due to poor communication between IT and management, creates information overload and distracts from critical insights. *Poor self-assessment of information needs* is the third bottleneck. Managers frequently struggle to specify the exact data they require, leading to excessive data requests and an overload that hinders effective decision-making. The fourth bottleneck, *ineffective use of information*, happens when quality data is available but not utilized effectively. Personal interests, unstructured processes, or cognitive biases can cause managers to overlook valuable insights, reducing the data's impact on performance. These bottlenecks highlight the need to align data with actual decision-making requirements to enhance organizational outcomes. To summarize, figure 3.3 depicts the four bottlenecks graphically in relation to each order. The numbers refer to the bottleneck described above.

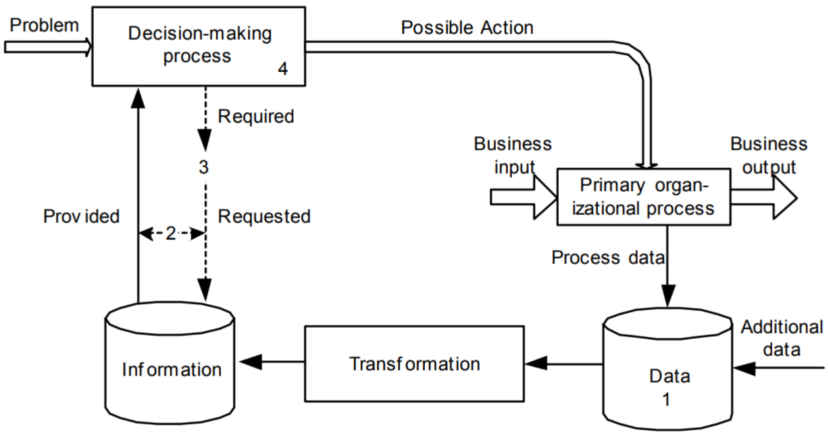



**Figure 3.3:** Positioning of the four bottlenecks. (Lohman et al., 2003)

The challenges identified in data-driven design management, along with the four bottlenecks from management information theory, can be combined to provide a comprehensive overview of obstacles affecting effective decision-making and how those challenges can influence situational awareness of the design phase.

**Table 3.1:** Overview of design challenges found in literature

| Bottleneck | Challenge | Description / requirement | Source |
|---|---|---|---|
| 1 | Lack of data visibility | Companies often have vast amounts of data but lack visibility into what is stored or newly generated, limiting its use in design-related decisions. | Wu et al., 2013; Altavilla et al., 2017; Arnarsson et al., 2018 |
| 1 | Difficulty leveraging available data | Designers struggle to utilize accessible data effectively, hindering innovation and efficiency in decision-making during the design phase. | Arnarsson et al., 2018 |
| 2 | Varied expert interpretations of data | Experts interpret data based on their backgrounds, causing variations in what criteria are relevant and which data should be analyzed. Models need to accommodate these differences. | Bertoni, 2018 |
| 3 | Decision-making with incomplete data | Design decisions are sometimes made with incomplete information. Models should balance including enough data to support decisions without giving a false sense of precision. | Bertoni, 2018 |
| 2 | Handling numerical and nominal data | The framework should handle both numerical and nominal data to provide a comprehensive picture of the design. | Bertoni, 2018 |
| 4 | Limited capacity to process complex data | Humans have limited capacity to process large amounts of complex information under time pressure. Models should simplify data visualization and interpretation. | Bertoni, 2018 |
| 1 | Complexity in data management systems | Organizations are not always equipped with advanced data management systems to handle large datasets | Wilberg et al., 2017 |
| 3 | Guiding users in data capturing | There is lack of clear guidelines for capturing the right data, making it more difficult for companies to meet design goals | Johnson et al., 2023 |

## 3.4. Design Development

This section distinguishes between the different stages of the design process, the milestones within the design phase, and the current methods used for managing these milestones.

### 3.4.1. Design process

The development of a project's design goes through several phases. Throughout the design stage, the design becomes progressively more detailed. In the Netherlands, the design process for construction project is typically divided into four main phases: Concept design (SO), Preliminary Design (VO), Final Design (DO), and Detailed Design (UO). These phases guide the project from initial ideas to detailed drawings for construction. In the first phase (SO), the focus is on identifying basic requirements for the project. The main goals of this phase is to establish the project's scope and vision. In the second phase (VO), the concept is further refined. The objective here is to develop the initial design and confirm that all design requirements are in line with the project goals. This phase ensures that the design is moving in the right direction and sets the foundation for more detailed work. The third stage (DO), focuses on finalizing the design. All design aspects are considered, and the design is essentially frozen. The objective here is to ensure that the design work has progressed sufficiently to include all required elements and that any critical interfaces are defined. In the last phase (UO), the design is further refined for technical details. This phase ensures that the design is ready for execution (BNA, n.d.).

### 3.4.2. Design milestones

In project management, project schedules are essential for managing, executing, and monitoring various tasks across projects. A key part of these schedules is setting milestones, which is a valuable tool for tracking progress. Today, most projects include detailed time plans to help keep everything on track. Halloran (2010) describes a project schedule as ”a road-map” that outlines tasks and estimates their duration's, guiding the project in the right direction. As noted by Magalhães-Mendes, (2011) the project schedule forms the foundation of the overall project plan. Yet, developing reliable and realistic schedules remains one of the most difficult aspects of project management (Gowan et al., 2006). Douglas,(2004) adds that project schedules help measure progress toward the project's goals. In addition, Wigal, (1990) points out that having a clear schedule is necessary to track progress and manage delays effectively.

Milestones play an essential role in structuring and monitoring project schedules. According to Hormozi and Dube (1999), tracking milestones is an effective method for maintaining control over the project timeline. They serve as checkpoints that reflect whether the project is progressing as planned. As highlighted by Tausworthe (1980), the number of completed milestones at a given point in time can be used as a measurable indicator of progress toward the final objective. Delays in reaching these predefined points can result in broader schedule slippage. In this context, Wallin et al. (2002) describes a milestone as a scheduled event that signifies the completion of one or more critical tasks, offering a tangible way to assess development.

In the context of project management, milestones mark the end of key project stages. According to Laporte et al. (2012), milestones are typically positioned at the end of phases and that milestones have no duration but serve as checkpoints in the project timeline, often referred to as activities with zero duration. According to Kampe (2012), good milestones share key characteristics, including the following elements: 1) Specific, 2) Measurable, 3) Achievable, 4) Relevant, and 5) Timely.

Research by Sunmola (2021) examined twelve types of milestones. However, not all of those types are applicable when creating a schedule for the design phase specific. The following five milestones are most applicable when creating a schedule for the design phase.

- **Completion and approval milestones:** During the design phase, significant elements, such as the preliminary or definitive design, will require formal approval. These milestones mark the completion of a design stage.
- **Decision milestones:** These are critical for determining the direction of the design. Decisions at key points, such as moving from concept design to detailed design, or the approval to proceed with technical specifications, are essential in the design phase.
- **Management milestones:** As the design phase often requires close coordination between different teams (e.g., architectural, structural, and systems design), management milestones will ensure that logistics, resources, and timelines are monitored, ensuring progress aligns with the project plan.
- **Soft vs. hard milestones:** The design phase may involve soft deadlines for internal reviews and hard milestones for delivering finalized designs or meeting contractually set deadlines for client approval.
- **Communication and report milestones:** Regular updates and design reviews are important. These milestones could involve delivering status reports to stakeholders, updating them on design progress, and receiving feedback for iterations.

### 3.4.3. Stacey matrix and design phase complexity

The Stacey Matrix is a conceptual framework used to understand the complexity of decision-making by mapping situations along two axes: the level of certainty (about technical solutions) and the level of agreement (among stakeholders) (Stacey, 1996). It distinguishes between simple, complicated, complex, and chaotic project environments, each requiring a different management approach. In the design phase of infrastructure projects, uncertainty is typically high and stakeholder alignment is still developing, particularly during the preliminary design (VO) stage. These conditions place the project in the complex or complicated zone, where fixed schedules and rigid milestone tracking often fall short (Cicmil et al., 2006; Bosch-Rekveldt et al., 2011). Instead, adaptive planning, iterative development, and close stakeholder collaboration are more effective strategies.

As design progresses into the final (DO) and detailed (UO) phases, uncertainty and disagreement decrease. The project then moves toward the simple or complicated zones, where structured planning and milestone control become more applicable (Stacey, 1996; Snowden and Boone, 2007). Applying the Stacey Matrix in design management highlights the need for dynamic workflows, continuous feedback loops, and tools that support traceability. It reinforces the idea that complexity should not be treated with rigid control but instead managed through flexibility, systems thinking, and phased convergence toward certainty and agreement.

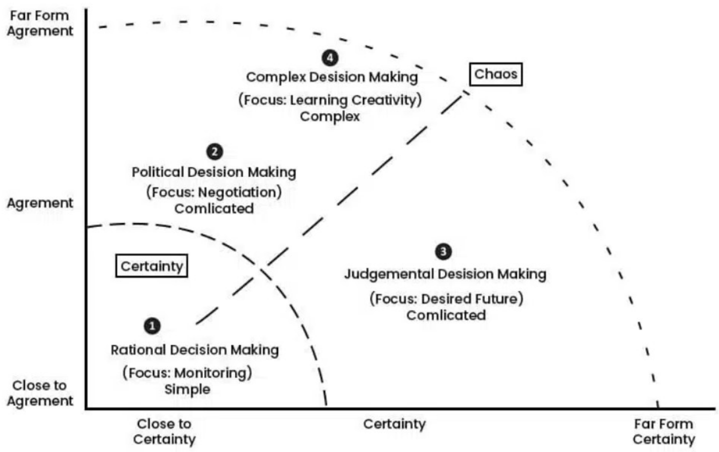



**Figure 3.4:** Stacey framework, (Stacey, 1996)

# 4

# Interview findings

*This chapter presents the results of the data analysis that contributed to refining the problem identification. The insights from the expert interviews build upon the initial theoretical understanding and uncover practical challenges that were not fully addressed in the original problem statement (Chapter 1). These findings retroactively sharpen the problem definition, in line with the iterative nature of the Design Science Research Methodology (DSRM), and serve as the concluding step of Phase A.*

## 4.1. Interview outcomes

In this section, the outcomes of the semi-structured interviews are presented. The interview data is sorted to display the familiarity with the concept of data-driven design management, the challenges and trends, the factors that lead to delay, and indicators that can say provide more insight into the design process. Codes are clustered to create themes, each theme exist out of one or multiple subthemes.

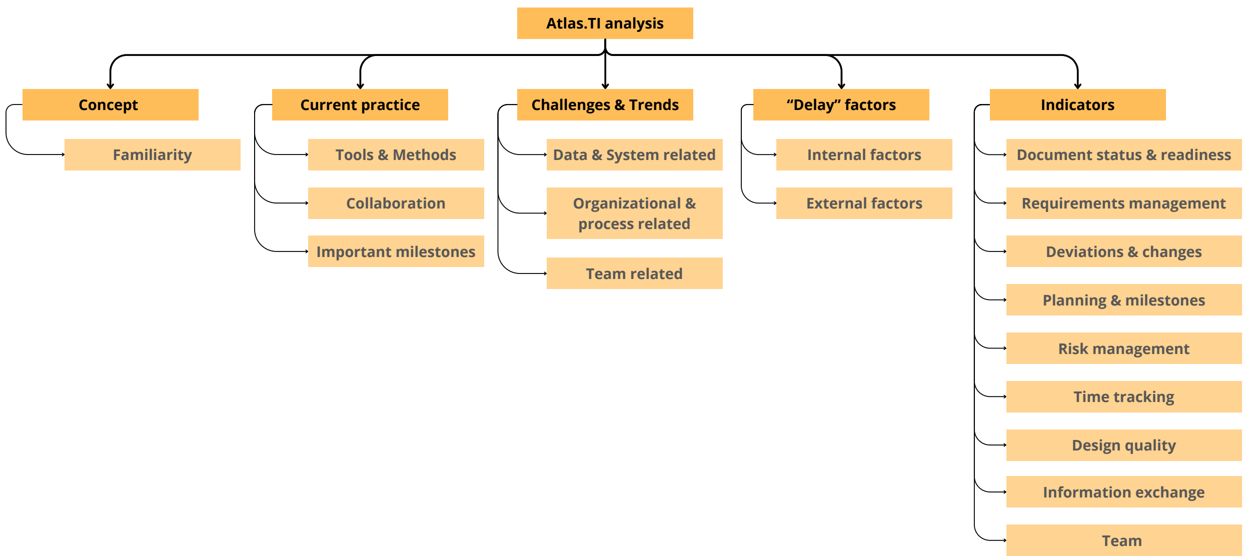



**Figure 4.1:** Themes obtained from data analysis using ATLAS.ti

### 4.1.1. Familiarity with the concept of data-driven design management

The interviews reveal diverse levels of familiarity with the concept of data-driven design management among the participants. While some recognized its potential to enhance project insight and decision-making, many were uncertain about its practical implications. As mentions by one interviewee, *"Data-driven design management, I can form an image of it, but I'm not sure"* (Design Leader, X5). This statements highlights that parts of the concept are recognized, its broader scope is not always fully understood. This lack of clarity was further emphasized by another interviewee, who described their reaction as mixed:

*"Well, my first thought was no. And then I thought, yes, yes, kind of a little bit. [...] So I think there are a lot of questions and answers all at once. Look, I see it. So, do I know it? Well, no, not really." (Design leader, X8)*

One participant admitted, *"I know the term vaguely, but it was new to me. I Googled it and realized the underlying processes are somewhat similar to what we do as part of our regular work."* Another reflected, *"I can imagine something about it, but it doesn't directly ring a bell."*

These reflections highlight both the potential and also the lack of knowledge about the concept. Participants often acknowledge that the concept sounds promising and could help them in their daily work, but they lacked a comprehensive understanding of how these could integrate into broader design management processes. For instance, one participant shared, *"My need is for a complete dashboard for design management—not just Relatics, but something that integrates planning and resource usage."*

These findings support the findings of the scientific part in understanding and applying data-driven design management, particularly in integrating data use into management practices. This lack of clarity presents an opportunity to better define the concept and its practical implications.

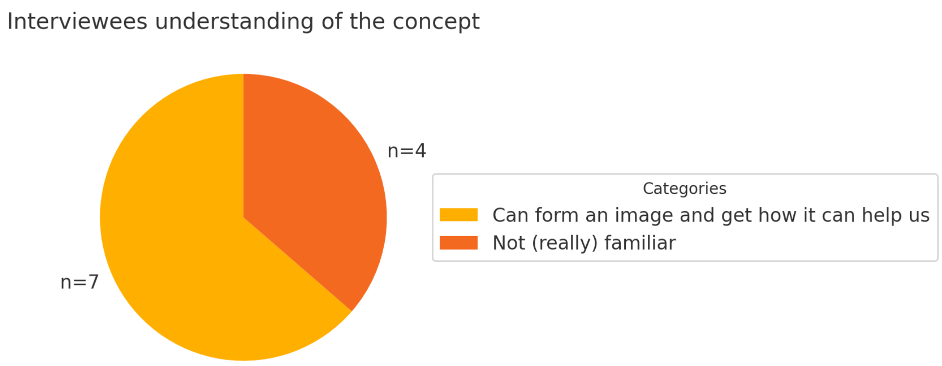



**Figure 4.2:** Problem configuration

## 4.2. Challenges and Trends

Managing the design process is a crucial yet challenging task within construction projects, particularly during the design phase. Insights gathered from interviews reveal various challenges that can be broadly categorized into three main groups: (1) data and system-related, (2) organizational & process challenges, and 3) team dynamics and collaboration. Understanding these categories provides a foundation for analysing and addressing the complexities of the design process. It is important to note that the challenges are closely aligned with delay factors, which will be discussed in the next section. Challenges often refer to broader, structural issues or limitations that hinder the project, while delay factors focus on the more immediate causes of delays within specific processes, such as design.

### 4.2.1. Data and system related

Although nowadays a lot of project data already is being captured, a recurring theme in the interviews was the inconsistent and sometimes unstructured approach to **data collection and structuring**. The information overload, caused by the overwhelming volume of project data, poses challenges to knowledge reuse, real-time monitoring, and learning within Heijmans. Design leader X1 mentioned that the biggest challenges they face lie in elevating data to a more abstract level, enabling the collection of comparable data. Structuring this data in a way that ensures it remains easily retrievable for future use is, according to them, the most significant hurdle at present. The excessive data can create confusion, making it difficult to identify relevant knowledge or determine which data should be collected. Another explained that the process is not as efficient as it should be, describing the concept of data-driven approaches as an ongoing learning process. Additionally, interviewees highlighted the difficulty of structuring and storing information consistently across the team, emphasizing the need for specific attention to address this challenge. This is put forward by an interviewee:

*"What is, of course, important is that data is readily available and accessible to everyone." (Design Manager, X9)* which is further elaborated by another interviewee, *So that would indeed be desirable. However, it does require upfront insight into how to store documentation and what you ultimately need to deliver for that database. And on top of that, ensuring that it actually gets done in the end". (Design Leader, X11)*

Without a clear prioritization system, identifying critical and reusable knowledge becomes difficult. Additionally, challenges arise related to decision-making with incomplete data and concerns about the reliability of the data collected. Further, interviewees pointed out that it is challenging to obtain a clear overview of project progress, the status of documents, and other relevant parameters. This is emphasized by an interviewee, who addressed the importance of clear visualization to make the available data more accessible and understandable (Design Leader, X5). To address these challenges, a clear and effective use of software would be preferred. However, some interviewees also highlighted issues related to the systems they currently use. One noted,

*"The system is also evolving, so we might eventually switch to a different application. You already hear about various planning applications, different document management systems we've encountered, and even different versions of Relatics." (Design Leader, X1)* Another interviewee added, *"The software simply isn't advanced enough yet."*

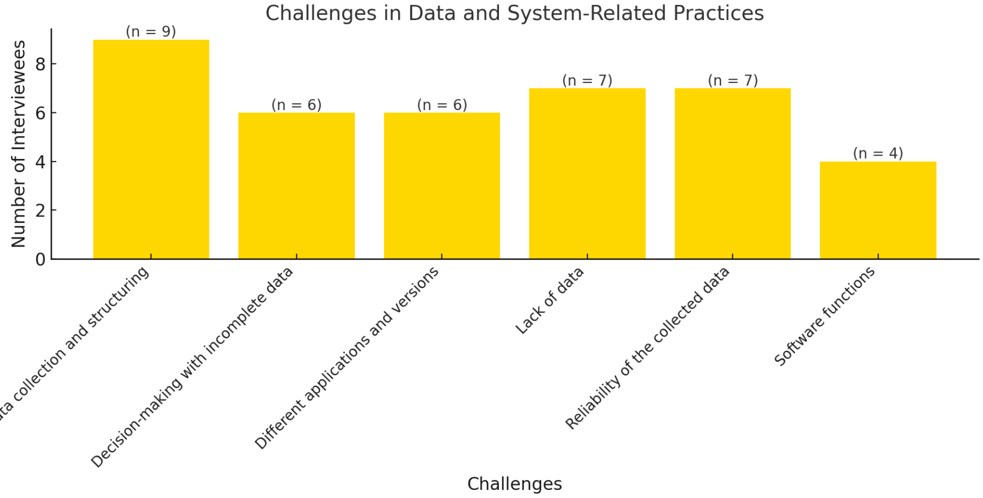



**Figure 4.3:** Data & System related challenges mentioned by the interviewees

### 4.2.2. Organization & Process related

In addition to the challenges related to data & systems, several organizational & process challenges have been identified that can impact progress and therefore results in delays. The following section will discuss this challenges.

One of the most frequently mentioned challenge is the **lack of consistency** in how data is stored and structured. Employees use different systems, such as SharePoint, M-Files, Relatics, and Autodesk Construction Cloud (ACC), each with its own data storage methods. Also not every system is used in each project. This leads to inconsistencies and can makes it difficult to compare and analyse data. It is crucial that all data is stored in a standardized manner to make it usable. Interviewee X5 noted that while there is a standard structure for entering data, differences between systems persist, this is supported by interviewee X10 which states that data is recorded differently for every project. A general statement about this challenge is provided by interviewee X11 and X4:

*"Yes, but of course, all your data from previous projects would need to be recorded in the same way to be able to draw any conclusions from it." (Design leader, X11)* and *"And also, how should you store that data? Because if everyone works in a different way, you may collect a lot of data, but you won't be able to compare it."(Senior Design Manager, X4)*

Many interviewees expressed a need for a **clear overview of project progress**. Although the information is often present in the systems, it is difficult to find and filter effectively. There is a strong demand for simple visualizations and dashboards to quickly gain insights into project status. Interviewee X5 and others pointed out that the information exists in the systems but is hard to filter, and a simple overview would be helpful. Multiple interviewees mentioned there need for a overview that can help them in there daily work. This challenge is summerized by interviewee X11: *"Well, what would help me is simply having an overview of the design progress in terms of: Where do we stand with the requirements, where do we stand with the interfaces, and where do we stand with the risks? I would really like to see all of that at a glance." (Design Leader, X11)*

There is **resistance to adopting new systems and workflows**. Employees often have their own established methods and are not always willing to adapt. This resistance leads to inconsistencies in data entry and usage. Interviewee X8 remarked that the goal should not be to force everyone to work the same way but to ensure transparency about how each person works. The adopting of a new system, but the resistance to use this systems for new workflows is put forwarded by interviewee X6: *"We review for this project for the first time in Relatics. I think it's fantastic because it works really well. But for almost everyone else, it takes a lot of effort—they find Relatics overwhelming and difficult." (Senior Design Manager, X6)*

Projects are becoming **increasingly complex**, resulting in an overwhelming amount of data that is difficult to manage. This data overload makes it challenging to maintain an overview and locate relevant information. There is a need for simplified and visual representations of data to reduce complexity. Interviewee X1 noted the difficulty of structuring and documenting everything at the data level, while interviewee X5 highlighted that as projects grow larger, there is an increasing need for simplification and visualization. This challenges is summerized by interviewee X11: *"Yes, you also don't want it to become so overwhelming that everyone loses track. Or that you collect so much data and have so many tools that no one knows what they're doing anymore."(Design Leader, X11)*

There is a **lack of focus on analysing collected data and optimizing processes**. Priority is often given to completing projects rather than improving processes through the use of data. Interviewee X1 observed that there is little attention paid to learning from data, and its value is not immediately apparent. Interviewee X8 summarized that the goal is to make data accessible in such a way that progress can be viewed at a glance. *"But the term data-driven implies that you actually use that data to inform your design management. And at the moment, I'd say that goes a step beyond what we're doing in practice." (Design Leader, X1)*

There is a **shortage of specialized engineers and designers**, making it challenging to complete projects on time and efficiently. Interviewee X5 highlighted that the market is limited, making it difficult to find the right people. Similarly, interviewee X8 noted a lack of individuals with specific engineering expertise. This challenges is described by interviewee X5: *[...] There is the issue of limited capacity.*

### 4.2.3. Team related

In addition to the challenges described above, the team can have a significantly affect on project outcomes. First, there is the aspect of **communication and collaboration**, which often proves to be a pain point. Effective communication is crucial for a smooth design process, but in practice, it frequently becomes an issue. A lack of clear communication leads to misunderstandings, delays, and errors in the final design. It is essential for disciplines to align their information effectively and ensure that everyone works with the most up-to-date document versions. Interface meetings play an important role here, as they help to align all team members and resolve potential conflicts in a timely manner.

Additionally, **team dynamics and expertise** play a key role. The personalities, work methods, and capabilities of team members directly impact progress. Some team members are naturally more optimistic about their schedules than others, which can lead to delays when their estimates are unrealistic. Conflicts or a lack of effective collaboration within the team also hinder the process. Moreover, it is crucial to have sufficient expertise within the team, as well as a degree of process discipline in following established procedures. A general statement about this challenge is put forward by interviewee X10: *"Yes, and I think we quite heavily rely on the knowledge and experience of the designer themselves, trusting that they are well-equipped to achieve it."*

Finally, there is the aspect of **dependencies and information exchange**. The design process often relies on input from various disciplines and external parties. When the delivery of information is delayed or not provided at the right time, it has a direct negative effect on the schedule. It is important to identify these dependencies and establish clear agreements about when specific information is needed. The dependencies of the team on other disciplines is described by interviewee X3: *"[...]. Some disciplines work... It's all iterative, so they first need some data, then they refine it again. The danger is that you might not have updated or refreshed the old data with the latest input."*

# Phase B

## Objective for a Solution

# 5

# Defining Monitoring Objectives and KPIs

*Building on the problem identification in the previous phase, this chapter explores the monitoring needs that must be addressed to improve situational awareness and milestone tracking during the design phase. The goal is to identify what information should be monitored, how it can be derived from existing systems, and which indicators are most relevant for practice.*

*The analysis in this chapter follows a dual approach. First, a literature-based investigation is conducted to identify commonly used performance indicators and monitoring concepts in data-driven design and project control. Second, practical insights are drawn from the case study and expert interviews to capture current practices, limitations, and stakeholder needs in the field. Together, these perspectives form a comprehensive foundation for defining the requirements and objectives of the artefact to be developed in the next phase.*

## 5.1. Monitoring needs from literature

This section investigates monitoring needs during the design phase by drawing on literature related to performance measurement, KPIs, and information flow. These monitoring needs go beyond performance measurement—they directly support the restoration of situational awareness within design teams. By systematically capturing milestone statuses, document readiness, verification cycles, and requirement coverage, the selected KPIs contribute to all three levels of situational awareness: perception (real-time visibility), comprehension (understanding implications), and projection (anticipating risks). In this way, the monitoring framework forms a critical foundation for enabling proactive design management in fragmented, data-rich environments.

### 5.1.1. Measuring performance of the design phase

There are two primary ways to measure success in a project: project performance and process performance. The concept of project performance has been studied extensively, and traditionally project performance is measured based on time, costs, and quality, i.e., the Iron Triangle (Atkinson, 1999b). These three criteria remain well-known to determine whether or not the project is delivered as intended (Pollack et al., 2018). In contrast, process performance examines the efficiency of individual activities within the project, such as resource utilization, lead times, cycle times, and error rates (Haponava and Al-Jibouri, 2010). Both approaches are crucial for not only achieving project goals but also optimizing the processes that drive these outcomes.

Gaining control over the design phase requires effective monitoring of its key sub-processes, as this increases the likelihood of achieving overall project goals. Numerous studies have shown that the construction industry continues to struggle with inefficiencies. While some of these challenges stem from overly ambitious project plans and unrealistic objectives, many are rooted in issues related to process performance (Haponava and Al-Jibouri, 2010). Within the design phase, workflow is often understood as the timely delivery of relevant information to the appropriate stakeholders. Traditional planning and management methods applied at this phase often fail to address workflow variability, which leads to sub-optimal cycle times, higher costs, and increased rework, all of which negatively impact both design and construction performance. Unlike the construction phase, where performance assessment through indicators like schedule, costs, and quality is a global practice, the design phase typically lack such comprehensive performance assessment (Chan et al., 2004). Evaluation in the design phase is often limited to compliance with delivery milestones.

However, integrating Early Warning Systems (EWS) and KPIs offers an opportunity to enhance this evaluation. EWS provide proactive alerts that identify potential risks or deviations in key performance metrics, while KPIs establish measurable benchmarks for process efficiency and project performance. By aligning EWS with KPIs, projects can track productivity more effectively during the design process, ensuring that planning is consistently monitored and deviations are addressed promptly.

### 5.1.2. Key Performance Indicators (KPIs)

Key Performance Indicators (KPIs) are essential tools for tracking processes to effectively monitor and manage performance. Research by Herrera et al., (2019) categorizes these indicators into three stages of the design process: *during the design, at the end of the design, and after the design.* Given the focus of this research on the design process and preventing delays, only the "during the design" stage is considered, as this stage provides time-related insights. The KPIs during this phase are measured on a weekly basis.

**Table 5.1:** Performance indicators (adapted from Herrera et al., 2019)

| Stage | Indicator | Description |
|---|---|---|
| During the design | Rework | Percentage of hours that the design team spends working on a task that had already been done (rework) in proportion to the total time spent working on the project during that week. |
| | Latency | Average waiting time that exists between the request and delivery of information between two or more project members. |
| | Quality defects | Number of failures, errors, or nonconformities detected in the design process per week. |
| | Commitment achievement | Percentage of plan completed within the week. |

Another study by Haponava and Al-Jibouri, (2010) conducted research on the performance of the design process in relation to project end-goals, which are defined as the key objectives determining whether a project is successful. While most projects focus on controlling the final outcome, it is equally important to measure and manage the processes within the design phase to ensure overall success. Various attempts have been made to establish construction performance measures, resulting in a set of KPIs. They developed a model that identifies these KPIs for managing the design phase and linking them to end-project goals. By concentrating on process-based KPIs, project managers can better control the design process, increasing the likelihood of project success. Their model demonstrates how performance during the design stage directly impacts the likelihood of achieving the project's overall objectives.

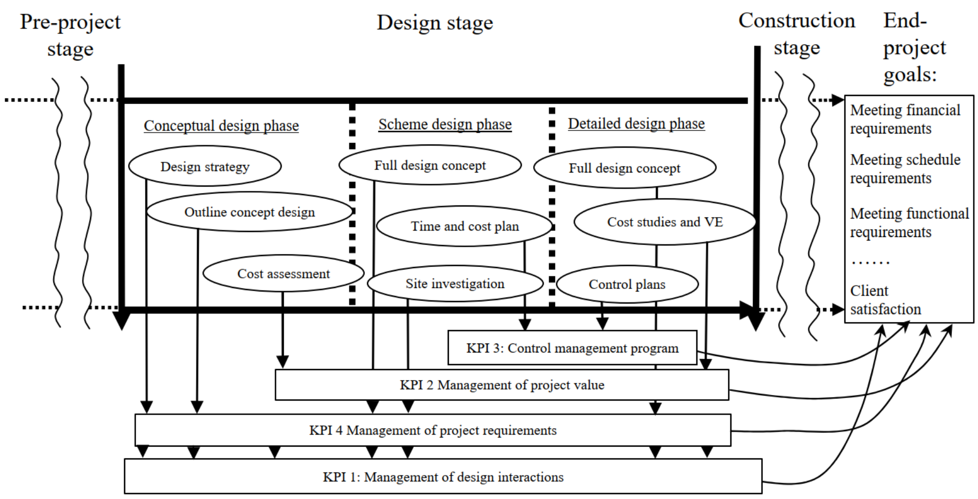



**Figure 5.1:** Relationships between the sub-processes within the design stage and the end-project goals. (Haponava and Al-Jibouri, 2010)

They highlight four critical KPIs that are essential for managing the design phase in the Dutch construction industry, improving the likelihood of project success through effective process management. In addition to these four KPIs, the study identifies several key elements that need to be controlled for each KPI. Those elements are displayed in table 5.2:

**Table 5.2:** Key Performance Indicators (KPIs) and main elements to be controlled (adapted from Haponava and Al-Jibouri, 2010)

| KPI | Main elements to be controlled |
|---|---|
| **Management of design interactions:** | Relationship between design teams<br>Degree of influence of project<br>Methods of interaction/cooperation<br>Decision-making process<br>Timeframe for interactions<br>Plan of communication<br>Continuous involvement<br>Keeping systematically informed |
| **Management of project value** | Clear description of functional requirements<br>Possible ways in achieving the requirements<br>Project costs<br>Potential project risks<br>Buildability<br>Project performance |
| **Control management program** | Deliveries for the following phases<br>Information streams<br>Program time milestones<br>Work Breakdown Structure (WBS)<br>Methods of meeting project objectives |
| **Management of project requirements** | Understanding of product requirements<br>Commitment to product requirements<br>Identification of bidirectional traceability in requirements<br>Maintenance of bidirectional traceability in requirements<br>Inconsistencies between project plans and product requirements<br>Establishment and maintenance of product performance with product requirements, design, and operational information |

Based on the focus of this research, the two most critical KPIs for data-driven milestone management are Management of Design Interactions and Control Management Program. The Management of Design Interactions KPI is essential because effective communication and coordination between design teams significantly impact the speed and quality of decision-making. Miscommunication or delays can result in misaligned designs, rework, and missed milestones. By tracking and optimizing these interactions through data, teams remain synchronized, ensuring that the schedule and quality of the design process are maintained. The Control Management Program KPI is critical as it systematically monitors the project's adherence to planned milestones. It facilitates early detection of schedule deviations, allowing for timely corrective actions. By tracking milestone adherence and information flows, this KPI ensures the project remains on track, providing necessary feedback for real-time adjustments and minimizing delays and disruptions in the design phase.

### 5.1.3. Flow of information

In the context of the construction industry, managing information flow and ensuring timely delivery of design milestones are critical to achieving project success. While Building Information Modeling (BIM) is a widely adopted tool for managing processes, it is not the only solution. Systems like Relatics, M-files, and Autodesk Construction Cloud (ACC) can offer robust alternatives for managing the design phase without the dependency on BIM models. These systems can help to organize data, track milestones, and there optimize the decision-making process.

Timely and efficient exchange of product-related information among team members is essential for maintaining progress in design projects. Morgan and Liker (2006) identify two primary forms of waste in product development: one arising from inadequate engineering, which leads to poor product or process performance, and another rooted in inefficiencies within the development process itself. As noted by Freire and Alarcon (2002), emphasizing flow and value creation offers a useful lens through which the development process can be better understood. This perspective serves as a foundation for both analysis and ongoing improvement.

The importance of improving information flow in design management has been widely acknowledged in the literature. A common starting point involves modeling processes and visualizing information exchange using tools such as data flow diagrams (DFD), unified modeling language (UML), and structured analysis and design technique (SADT), among others (Lee et al., 2007). The iterative nature of design activities has been observed in empirical studies (Smith and Tjandra, 1998) and formally represented through methods like the Design Structure Matrix (DSM), originally developed by Steward. This approach has laid the groundwork for extensive research on optimizing design workflows. However, comparatively little attention has been given to tracking or quantifying the actual information flow between designers within specific stages of the design process.

Sacks (2016) introduces a framework that distinguishes between *process flow* and *operations flow* in construction, where process flow involves sequencing activities at a single location, while operations flow tracks how tasks move between locations. Although this framework is specific to construction, its principles can enhance the design phase by ensuring information flows continuously between various teams. In the design process, professionals convert inputs such as requirements, ideas, and specifications into detailed design documents. Unlike traditional production processes that generate physical outputs, design depends on the continuous and accurate exchange of information. Inefficiencies or the use of outdated data can easily lead to delays and hinder project progress.

Ballard (2000) and Huovila et al. (1997) expand this view by treating the design phase as a production process, using Koskela's TFV (transformation, flow, value) theory (Koskela, 2000) to highlight the importance of structured information flow. Here, information is transferred in discrete packets that can be stored, copied, aggregated, or divided, facilitating structured movement across the design process. By maintaining continuous and transparent data exchange among stakeholders, design milestones can be met more consistently, reducing rework and minimizing delays.

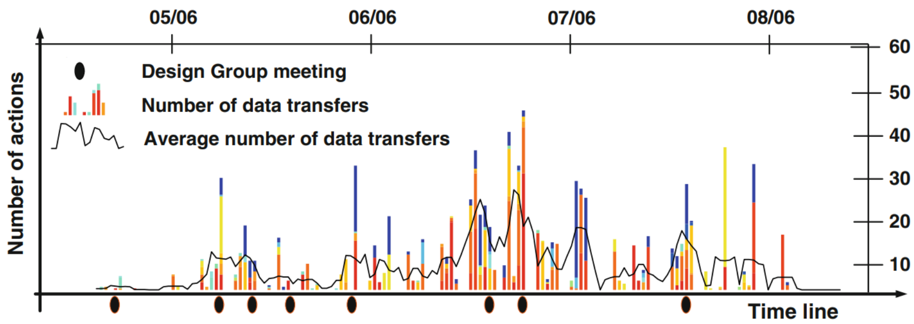



**Figure 5.2:** An example of how data from data-management system could be visualized in relation the design timeline. (Tribelsky and Sacks, 2010)

While the analogy to product flow is not completely perfect, as it requires handling information that may be provisional or iteratively refined, it provides a framework for milestone management within the design phase. This approach enables tracking of essential metrics, such as verifications and validations, and supports the application of principles from the theory of constraints (Goldratt 1997) and lean thinking (Womack and Jones 2003) to identify bottlenecks and optimize information flow. Integrating these metrics into the design process facilitates robust milestone tracking and strengthens control over project outcomes, ultimately enhancing project performance in the design phase.

During the design phase, multiple independent designers and consultants rely on information from one another. Applying lean principles such as reducing batch sizes, shortening cycle times, and limiting work in progress can help improve the flow of information and reduce inefficiencies. However, a major challenge is the lack of standardized methods to measure and evaluate these information flows. This limitation hinders both process improvement and timely performance adjustments. As Drucker (2001) emphasized, effective management depends on performance indicators that are measurable, clearly defined, and relevant, as they help direct attention and effort toward meaningful improvement.

### 5.1.4. Key indices for information flow

Tribelsky and Sacks (2010) proposed a method to quantify information flow within the design process by introducing seven specific indices. These indices are rooted in lean principles and focus on key elements such as cycle time, work in progress, and the identification of bottlenecks. They are used to evaluate the generation, distribution, grouping, and other patterns of design information. To support the calculation of these indices, the authors introduced seven core concepts: information package, information item, information object, information attribute, action, project event, and information batch. These concepts are essential for consistently measuring and managing information flow throughout the design phase.

While these indices are primarily focused on the detailed design phase and were originally applied within the context of 2D CAD drawings, they offer a flexible structure that can be adapted to support information flow throughout the entire design process. Given the focus of this research on systems like Relatics, ACC, and M-Files, these indices can be repurposed to provide structured insights into data management and flow across all design stages.

Tribelsky and Sacks (2010) introduce seven indices that are used to quantify and manage information flow:

1. **Action Rate (AR):** Measures the frequency of information transfers (e.g., validations or approvals) per unit of time. High action rates indicate active information flow, essential for maintaining project momentum.
2. **Package Size (PS):** Quantifies the level of detail within each information package, such as the number of attributes or components. Larger packages may require more time for review, making this index important for workload management.
3. **Work in Process (WiP):** Tracks the number of available but unprocessed information packages, indicating potential backlogs. High WIP levels can signal inefficiencies that may delay milestone completion.
4. **Batch Size (BS):** Refers to the volume of information reviewed or validated in a single batch. Managing batch size ensures a steady flow and avoids overwhelming the system, aligning with lean principles.
5. **Development Velocity (DV):** Measures the rate at which information is developed and refined. High development velocity reflects efficient data progression, critical for staying on schedule.
6. **Bottlenecks (BN):** Identifies areas where information flow is constrained, impacting progress. Addressing bottlenecks is essential to prevent delays.
7. **Rework (RW):** Quantifies the amount of correction or revision required, reflecting data quality. High rework levels indicate issues with initial accuracy, potentially disrupting project timelines.

| Index | Description | Symbols | Units |
|---|---|---|---|
| Action rate | The rate at which information is transferred | AR | Actions/time |
| Package size | Quantifies the level of detail of information packages | PS | Information attributes |
| Work in process | The number of available but unused information packages | WIP | Information packages |
| Batch size | The batch volume of information transferred | BS | Information attributes |
| Development velocity | The velocity of information development as represented by accumulation of detail | DV | Information attributes/time |
| Bottlenecks | Identifies possible bottleneck partners in the process at any given time | BN | |
| Rework | Quantify the rework included in information packages. | RW | Information attributes |

**Figure 5.3:** Information flow indices. (Tribelsky and Sacks (2010))

## 5.2. Monitoring needs from practice

This section presents insights into monitoring needs during the design phase based solely on expert interviews conducted within Heijmans. While Section 5.1 established a theoretical foundation using literature, this section captures how design teams currently manage milestones, monitor progress, and use performance indicators in practice.

### 5.2.1. Current practice of milestone management

During the interview, the interviewees were asked to provide an overview of the processes applied to manage and monitor milestones. The interviews provided valuable insights into how milestones are currently managed within Heijmans. The main theme is divided into three sub-themes; 1) Tool & methods, 2) Collaboration across disciplines, and 3) Important milestones.

**Tools & methods**

When focusing on milestones, the tools used play a crucial role in influencing the efficiency and accuracy of project planning and therefore as well as the tracking and monitoring of progress throughout the design phase. From the interviews, it became clear that software as Primavera, MS Project, and Excel are mostly used. However, the results also showed the each tool serves a specific purpose within the design process, tailored to the different needs and aspect of each step in the process. The importance of having a good planning is highlighted by multiple interviewees:

*"In principle, always with a schedule. A schedule is essentially your steering mechanism"*, which is further elaborated, *"But a schedule, you can't do anything without a schedule. It's very crucial because a schedule is simply the communication tool between parties. But it's also something you use to guide and manage". (Design Leader X10)*

The selection of tools used in project management often depends on the complexity of the project. At the management level, planning is typically conducted using Primavera, which provides an overarching framework for the project schedule. At the design level, however, it is common for individual design disciplines to work in MS Project, managing their specific tasks independently. In this workflow, the comprehensive planning created in Primavera serves as an integrated baseline, while MS Project allows each discipline to develop more detailed task schedules. To simplify communication, these plans are often translated into Excel sheets or tables, providing a clear weekly overview of responsibilities and progress for the team. Almost every interviewee emphasized that an overarching integral plan serves as the foundation for every project. Depending on the project's size, this integral plan is further broken down into specific components, often managed using tools such as MS Project and Excel. This way of working is explained by an interviewee:

*"Basically, it starts with creating an integral plan for your design and then determining whether you can run the VO, DO, and UO phases in parallel across disciplines. If that's not possible, you take a closer look at what is needed for one discipline to complete its tasks while another continues to progress. (Senior Design Manager, X6)"*

After discussing the planning tools used, the interview focused on identifying the current methods for managing the project planning and the milestones outlined within it. Insights from the interviews reveal a number of methods currently used. A method highlighted by several interviewees is **lean planning**. This approach is used to provide specific insights into the tasks required by each team, ensuring that the rest of the team can progress with their work efficiently. As a number of interviewees explain lean planning as a method they use for tracking progress, they also often mentioned that they don't use digital tools for that, but use the traditional way of using "sticky notes ". The necessity of using lean planning was explained by interviewee design Leader, X7:

*"It's not very practical for everyone to pull up a large Primavera schedule on the screen when you want to show someone what they need to do that week." (Design Leader, X5)*

Another approach highlighted during the interviews is the **document planning method**, which provides a structured framework for organizing project documentation. This method is derived from the activity planning conducted earlier in the process. While some interviewees mentioned that certain design managers or leaders tend to combine document planning with activity planning into a single schedule, they acknowledged the importance of keeping the two separate. Maintaining distinct plans ensures that the document planning offers a clear overview of which documents need to be completed, linked to specific tasks and deadlines.

*"Documents and requirements that need to be elaborated in that phase are attached to it. Essentially, the completion of these documents and the verification of the requirements determine the progress." (Design Leader, X5)*

In addition to discussing the tools and methods used, interviewees were asked how they monitor the approaches they had defined earlier. Nearly all respondents emphasized that **meetings** serve as their primary method for tracking progress and monitoring milestones. These meetings can generally be categorized into two types: internal design team meetings, which focus on assessing the team's progress, and core meetings (kernmeetings), which evaluate the progress of individual disciplines in relation to others. One interviewee highlighted the central role of these meetings:

*"How do we monitor whether we achieve a milestone when introducing something like this? That often happens during a design meeting." (Design Manager, X3)* and *"I find it really interesting because I currently rely on conversations for tracking progress. But sometimes, you can be unexpectedly surprised—both positively and negatively". (Design Leader, X8)*

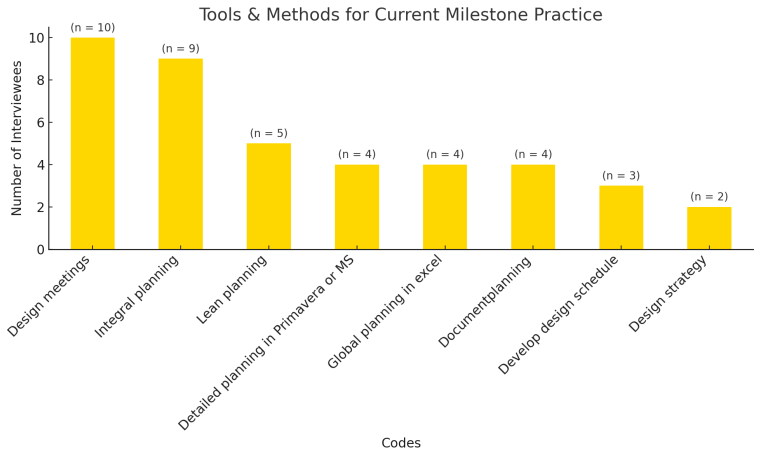



**Figure 5.4:** Tools & Methods mentioned by the Interviewees

**Collaboration across disciplines**
The analysis of current milestone practices provides several insights into effectively managing and tracking design processes. A key theme emerging from all interviews is the significance of discipline coordination. While milestones may vary in timing and scope across different disciplines, they ultimately converge toward delivering a unified project outcome, such as the completion of a preliminary design (VO). The findings highlight the critical role of an overarching integral plan in maintaining coordination among disciplines. From the interviews, it can be concluded that collaboration across disciplines is a crucial factor in creating and managing a realistic schedule. However, the tracking and management of this schedule are currently still predominantly reliant on meetings and conversations. This was put forward by several interviewees:

*"We discuss that with each other to see if it's feasible, and then we incorporate it into each other's planning."*, further elaborated by *"and in the overall planning, you simply have the direct links with each other."*

**Important milestones**
After establishing the current practices, interviewees were queried about their perspectives on important or critical milestones during the design phase. Almost all interviewees emphasized the completion of the three design phases (VO, DO, and UO) as crucial, often being the only milestones explicitly mentioned in the schedule. Additionally, several interviewees highlighted the significance of approval and validation milestones, such as the acceptance of design documents for VO (Preliminary Design), DO (Final Design), and UO (Detailed Design). Gate reviews were also noted as crucial moments, ensuring that product quality and progress are thoroughly assessed before proceeding to subsequent phases. The dependence on those general VO, DO, and UO milestones is put forward by an interviewee:

*"Yes, it is mainly VO, DO, and UO." (Senior Design Manager, X6)*, which is elaborated by another interviewee: *"Well, it really depends on what you consider a milestone. By milestone, I mean a milestone that has been agreed upon with the clients. This usually concerns the acceptance of the DO, UO, or VO, or whatever you have, but in any case, it's the acceptance of the design document." (Design Leader, X7)*

Despite the recognition of key milestones, interviewees also expressed concerns about the lack of clarity and definition in milestone planning. One interviewee noted that the planning often lacks specific milestones to guide progress, making it challenging to achieve the final goal efficiently (Design Leader, X10). This interviewee also highlighted the issue of having only a broad timeline, such as 12 or 20 weeks, where everything must be completed by the end. This approach was described as unmanageable, emphasizing the need for well-defined intermediate milestones to provide structure and facilitate progress.

Further, the interviews revealed varying perspectives on how milestones are approached and managed in the design process. These differences highlight the diversity in planning strategies and the challenges of aligning milestones across projects and teams.

Interviewee X8 prefers working with broad planning frameworks, monitoring progress through weekly team meetings. He emphasizes that setting specific weekly deadlines does not work for him. Instead, he relies on gauging the team's progress and assessing the feasibility of milestones during these discussions. Interviewee X5 noted that milestones are partly dependent on the project but also follow standard phases, such as VO (Preliminary Design), DO (Definitive Design), and UO (Detailed Design). He highlighted the importance of maintaining a consistent level of information across these phases but acknowledged that this often depends on team capacity. Interviewee X2 stressed the importance of having an integrated design plan that incorporates input from various disciplines and is aligned with the client. He emphasized that such alignment is crucial for maintaining a cohesive planning structure throughout the project. Interviewee X3 pointed out that each discipline has its own milestones, but there are also shared milestones that require collaboration. He emphasized that progress is discussed and coordinated during weekly meetings to ensure alignment across disciplines.

### 5.2.2. Delay factors

Delay factors are specific events or circumstances that directly cause delays in the design process and the achievement of milestones. While these factors are often project-specific, they can also follow broader, recurring patterns. They may stem from internal operations or external influences, such as clients or environmental conditions. These factors are closely linked to the challenges outlined in the previous section.

**Internal factors**

Internal factors significantly influence the efficiency and success of design processes, often stemming from within the project team. These factors can affect planning, communication, and overall coordination, posing challenges to timely and efficient project delivery. The internal dynamics of a team, such as capacity limitations, communication barriers, and coordination with execution teams, are critical to managing effectively. A list of the internal factors and their implication for the design process is given in appendix J.

**External factors**

While the external factors are outside the scope of this research, the interview results show that external factors play a critical role in influencing the progress and success of design processes. These factors often originate outside the control of the design team and can significantly impact project schedules and outcomes. They include client-driven changes, delays caused by external parties, and environmental influences, all of which introduce uncertainties and challenges. A list of the identified external factors is given in appendix J.

### 5.2.3. Key Performance Indicators

The final part of the interview focused on identifying whether KPIs are currently being utilized in practice and determining which indicators could provide meaningful insights into the design process. Based on the interviews, several indicators have been identified that can be used to monitor the design process. However, before mentioning the indicators, a outline of interview statements is given about the use of KPIs in the design phase. The interviewees have various statements about the use of indicators during the design phase, ranging from a lack of standardized indicators to the reliance on informal methods and the desire for more data-driven systems.

#### 5.2.3.1. Current indicators

During the interviews, interviewees were asked about which kind of data or indicators they currently used or would help them to monitor the progress throughout the design phase. Interviewee X10 mentions: *"Good question. Actually, I just want to say, we don't really have that, [...]."* It is also noted that progress tracking is primarily done at the tool level, such as using a planning system. While it is possible to derive KPIs from this approach, in most cases, it simply involves checking off tasks in the planning system to indicate completion (Design leader, X1 / Design manager, X4). The need for KPIs is put forward by an interviewee: *"But with that, it would be great to have a set of indicators, that allow you to see, for example, in this project, we notice there are this many changes, such as outstanding changes." (Design manager, X3).* An aspect that is mentioned several times during the interviews is to get insight in the team itself, as mentioned before, progress is ussally tracked in design meeting, the advatages of data-driven design is express by X5: *I am very positive about it, at least. I think we know a lot and have a wealth of data, but we are not using it enough—especially not to show others what we are working on. [...]. However, if we can at least show our team or clients where we stand and why we are there, that would already be valuable.*

Based on those statements, a recurring theme is the absence of standard dashboards or overviews that effectively measure progress in the desing phase. Interviewees, such as Designleader X5, emphasized that while information exists within systems, it often requires manual filtering. He highlighted the need for a simple and user-friendly overview, potentially implemented though tools like PowerBI. The reliance on subjective methods extends to progress tracking, which is frequently based on conversations and personal estimates rather than measurable data. For example, Designleader X10 noted that designers' feedback is often based on intuition, with no standardized method for measuring progress. Similarly, Design Manager X4 described how indicators are primarily discussed during meetings, and he often needs to search manually through systems like Relatics and financial tools to track progress. Design leader X11 echoed this, stating that much of the current monitoring is reliant on discussions and meetings. This followes by a lack of visibility into team activities was also identified as a critical issue, often resulting in unexpected delays or misalignments. Furthermore, while there is a strong focus on completing documents, this does not always serve as a reliable indicator of progress, as documents are often finalized late in the process. Despite these challenges, most interviewees recognized the potential of dashboards to visually present progress, provided they are simple and user-friendly. These dashboards could offer an overview of document statuses, requirements, and risks, enabling more transparent monitoring.

#### 5.2.3.2. Specific indicators

Within Heijmans, there is a clear desire to improve the design process by gaining better insight into progress through data. There is a strong need for real-time overviews in a dashboard to enable improved monitoring of progress. Currently, there is no standard for using KPIs in the design process, but there are ideas about which indicators could be beneficial. Several interviewees have shared ideas on which data is important to collect for more effective monitoring.

**Document status and readiness**

Multiple interviewees mentioned that it is crucial to habe insight into the status of documents and whether they are completed on time. This also included tracking whether documents have been reviewed. Maintaining document status in the systems is considered important. This is explained by an interviewee: *"Very simple overview of whether documents are completed or not. Or what status they have at a specific moment when they are supposed to have a status." (Design leader, X5)*

- **Document status:** Whether documents are completed and their current status at a specific time.
- **Number of documents in workflow:** How many documents are progressing through workflows.
- **Document lead time:** The time documents spend in the design process..
- **Number of document versions:** The number of times a document has been edited.
- **Document check-in/check-out:** Frequency of document check-outs.

**Requirements management**

Data on the status of project requirements, whether they have been completed, verified, and if any remain unresolved, is essential. Demonstrating compliance with the requirements is critical. This is put forward by an interviewee: *"But you might want to track progress, separate from whether it actually says you're at a certain percentage. How many of the requirements have already been checked off?" (Design leader, X8)*

- **Number of verified requirements:** Whether all requirements are verified and on schedule.

**Deviations and changes**

Recording the number of deviations or changes in a project is important as it can indicate risks and design quality. It may also highlight unclear project specifications. The need to track this is explained by: *And it would be great if you had a set of indicators, yes, the kind of indicators where you can see, okay, in this project we observe that there are this many changes, for example, outstanding changes." (Design manager, X3)*

- **Number of changes:** Tracking changes throughout the project indicates the stability of the scope and design. It's crucial to distinguish between internal changes and client-driven changes.

**Planning and milestones**

Monitoring progress against the schedule and achieving milestones is crucial. Milestones must be measurable ("SMART") by linking them to specific requirements. Deliverables for different design phases (VO, DO, UO) are regarded as key milestones. *"We don't have very clear milestones in the planning that help us achieve the final milestone." (Design leader, X10)*

- **Planned vs. actual Performance:** Monitoring adherence to the schedule and tracking progress helps assess whether the project is on track. This is often done through planning tools or weekly team discussions.
- **Milestone deadlines:** Ensuring that milestones like VO, DO, and UO deliveries are achieved on time, including internal and external completions.

- **Document planning:** Checking whether documents are ready on time relative to the schedule.
- **Lean planning:** Using lean planning to make tasks visible and manageable for teams.

**Risk management**
Data on risks, including the number of mitigation measures, is needed to monitor progress. Ideally, access to a risk dossier from a similar project would be beneficial. This is expressed by an interviewee: *"Yes. And what also comes to mind, for example, is risk management, which is also in Relatics. A certain risk profile is, of course, followed using the RISM method that is often included. That could also potentially indicate something about the reliability of your milestones at the start." (Design leader, X1)*

- **Number of risks identified:** Total risks identified during the project.
- **Risk profile:** The number of stakeholders involved can indicate the complexity and duration of processes.

**Time tracking**
Data on how many hours have been spent on a document or task can provide insight into progress and potential bottlenecks. It is worth noting that the output of hours worked often becomes visible only at the end of the process. *"If you can measure that 28 hours have been spent on this document, then it should probably be at 75% completion."*

- **Time registration:** Logging project hours and analysing their distribution over time.
- **Time spent per validation:** Measuring the time individuals spend validating documents and drawings.

**Design quality**
Data on the quality of the design, such as the number of times a drawing goes through verification rounds and whether key stakeholders have reviewed the design, is essential.

- **Number of validation rounds:** The frequency of validation rounds per document.
- **Number of comments:** The number of comments per document.
- **Document file size:** File size can indicate whether a document is complete.

**Information exchange and communication**
Data on the frequency of information transfer, file sizes, and how often rework is needed can reveal inefficiencies in information flows. The speed of information exchange between disciplines can be a key factor.

- **Frequency of information exchange:** How often and how quickly information is shared between teams and disciplines.
- **File sizes for exchange:** File sizes as an indicator of completeness and efficiency.
- **Revisions required:** Frequency of rework or revisions due to feedback.
- **Bottleneck identification:** Identifying points where information flow stalls.
- **Level of coordination:** The extent to which disciplines are aligned in sharing information.

**Team composition and capacity**
Data on the interchangeability of team members, the availability of critical personnel, team capacity, and workload can provide insights into progress.

- **Interchangeability of team members:** Flexibility in team roles and dependence on specialists.
- **Critical team members:** The number of critical team members.

### 5.2.4. Importance index

The interviews resulted a broad list of approximately 25 potential indicators. As an additional step in the research, the individual indicators identified during the interviews were evaluated by the same group of 11 participants. To identify those with the highest insight, an importance index was applied to rank the indicators based on expert feedback. This method prioritizes indicators according to their perceived relevance within the context of design management, making it particularly suitable for exploratory research. Although the sample size was limited, the importance index remains appropriate due to its focus on relative importance rather than statistical generalization.

Experts at Heijmans rated the level of insight each indicator provides into the design process using a 1 to 5 scale, where 1 indicated no insight and 5 indicated a high level of insight. These scores were converted into a 0 to 100 scale following the approach proposed by Zhang (2005), with the values 1 to 5 corresponding to scores of 20, 40, 60, 80, and 100, respectively. This enabled a consistent and transparent ranking of the indicators, forming the basis for selecting the most relevant metrics for each KPI group. The importance index is calculated using the following formula:

$$Importanceindex = I_i = \frac{20Ri1 + 40Ri2 + 60Ri3 + 80Ri4 + 100Ri5}{Ri1 + Ri2 + Ri3 + Ri4 + Ri5}$$

where:

- $I_i$ = importance index for the $i$th indicator,
- $Ri1$ = number of responses **"almost no insight"**,
- $Ri2$ = number of responses **"little insight"**,
- $Ri3$ = number of responses **"moderate insight"**,
- $Ri4$ = number of responses **"good insight"**,
- $Ri5$ = number of responses **"a lot of insight"**.

For example, for the indicator *"number of validation rounds"*, the importance index was calculated as follows:

$$I_i = \frac{(1 \times 20) + (40 \times 3) + (60 \times 5) + (80 \times 0) + (100 \times 1)}{1 + 3 + 5 + 0 + 1} = 54.0$$

A complete list of all assessed indicators, including their importance scores, can be found in appendix F. This list serves as a guiding reference for the development of the artefact presented in the next chapter, ensuring that the selected indicators are grounded in expert input and aligned with the practical needs of design phase monitoring.

# 6

# Design Process in Practice

*To fully understand the design process, the case-study used in this chapter serves as a reference to understanding how digital systems, verification processes, and milestone tracking are applied in actual projects. By examining the project's workflow, key challenges, and system interactions, the case highlights bottlenecks, inefficiencies, and opportunities for improvement. The insights gained contribute to the development of the artefact in Chapter 7 of this research.*

## 6.1. Case study

The case study has two main goals: to understand the current processes Heijmans follows in a project and to analyse these processes to find any inefficiencies. To do this, first an understanding of the data-systems used within Heijmans and identifying which data is stored in each system is necessary.

### 6.1.1. The project

The case-study that is covered in this part is the expansion of a highway in the Netherlands, which serves as a vital economic corridor connecting the country with its European hinterland. To keep the case study practical and manageable, the focus was limited to just one component of the project instead of the entire scope. The newly constructed underpass was chosen because it offers a clear and complete example of the design process while keeping the amount of data and complexity at a realistic level. This choice is based on several considerations:

- A large project involves multiple components, each with its own design, requirements, and dependencies. Analysing the entire project would introduce significant complexity with as result that it's harder to draw precise conclusions about specific processes or bottlenecks. Narrowing down the scope has as result that a more focused, in-depth understanding of the design lifecycle and related milestones can be reached. The analyse of the single component can then later be used as template for analysing other components.
- Each component within the chosen project generate a massive amount of design documents and data. Tracking the lifecycle of the entire project might lead to incomplete results. Focussing on one single components makes it possible to careful monitor deliverables, verifications, and approvals across the three design phases.
- A single-component focus provides a proof of concept that can be used on other components. Insights gained from tracking the underpass lifecycle can help develop a framework or methodology that can be adapted to different types of components.

## 6.2. Digital systems

It is crucial to gain a clear understanding of the data systems in use. This section focuses on the following data systems used at Heijmans: Relatics, M-Files/SharePoint, and Autodesk Construction Cloud (ACC). It provides an overview of the types of data stored in each system, the overall workflow within these systems, and the connections between them.

### 6.2.1. Relatics

The success of any project depends on the quality and accessibility of its information. Clear and immediate access to project data, such as risk and opportunities or requirements and verifications, helps prevent errors and inefficiencies. Effective management of information flow ensures smoother operations and better decision-making.

Relatics is a web-based platform designed to manage information. The platform allows users to present this complex, interconnected information in a structured and organized matter. To identify all the elements that need to be documented in Relatics, Systems Engineering is often employed. Relatics serves as a tool to structure these elements and trace them back to higher-level objects. This approach makes the interdependencies between various disciplines more clear, enabling efficient interdisciplinary collaboration. Relatics knows two kinds of users who can use the program, a functional designer who creates and configures a template and an end-user who actually uses the program. Before Relatics can be used a template needs to be configured for the end-user. The data within Relatics is organized into several categories that could be critical for tracking and managing project progress effectively. The data stored in Relatics is showed in figure 6.1.

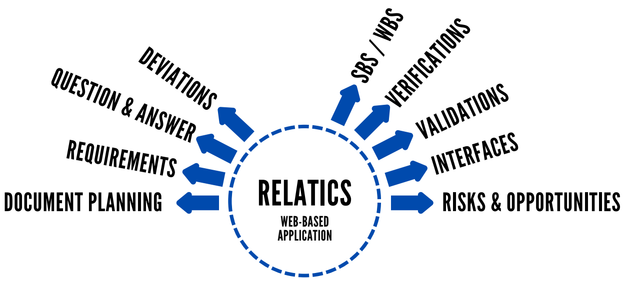



**Figure 6.1:** Data stored in Relatics

### 6.2.2. Autodesk Construction Cloud (ACC)

Autodesk Construction Cloud (ACC) functions as a collaborative Common Data Environment (CDE) used primarily for storing, managing, and reviewing design-related project data. Based on the case study, ACC is used in the following way:

1. It serves as the primary storage location for models and drawings. These files are developed and managed in ACC until they are formally approved. Once approved, they are transferred to M-Files, which acts as the official document management system (DMS).
2. It also acts as a secondary storage location for files that don't belong in M-Files, such as temporary or working documents.
3. Everyone involved in the project is expected to use ACC to view the latest models and drawings, ensuring that all stakeholders are working with up-to-date information.
4. ACC is also used to review documents and models, with tools for providing comments and tracking design feedback.

ACC keeps track of the most current versions of documents and models and includes useful features like version control, access rights based on user roles, and metadata tagging. This makes it a practical tool for monitoring how the design process is progressing. The types of data stored in ACC include:

- Design models and drawings (e.g., RVT, DWG, PDF) in both 2D and 3D formats
- Project documents that are not suited for M-Files
- Metadata such as file name, version, approval status, author
- Issues and review comments, linked to models or documents, mostly with pinpointed locations
- Workflow history

The folder structure in ACC typically follows ISO 19650 conventions: *Work In Progress (WIP), shared, published, and archived.* Depending on user roles, access to folders and actions (such as reviewing or commenting) may be restricted. When a document is ready for assessment, it is submitted through an internal review workflow. This includes selecting a predefined review route, assigning reviewers, and optionally linking issues or providing delivery context.

A key feature for tracking progress is the Issue module, which allows users to log design-related problems, such as clashes or open questions. These issues can be assigned to specific people, tied to specific models or documents, and given deadlines. This provides insight into which parts of the design still need attention, who is responsible, and whether any critical issues are holding up progress.

Besides formal issues, users can also make annotations in the form of notes, interface comments, reviews, and clash observations. Only the latter three are logged as official issues. Notes are meant for personal use and aren't linked to formal design status. This distinction is important, as only logged issues contribute to the traceable tracking of design maturity.

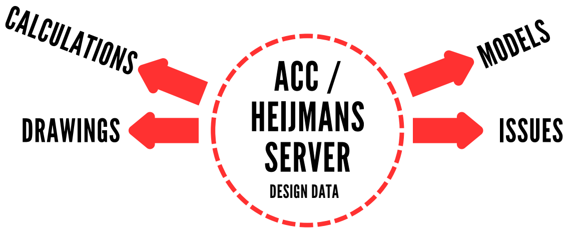



**Figure 6.2:** Data in Autodesk Construction Cloud (ACC)

### 6.2.3. Document Management System (M-files)

Document management ensures a seamless flow of information within a project. In this case, the information flow for the case study project has been analysed. According to the Heijmans Management System (HMS), a Document Management System (DMS) is implemented based on a M-Files environment. This system guarantees that:

- Documents are clear and traceable.
- Version control and document history are transparent.
- Documents are properly verified, authorized, and approved.

Implementing document management within Heijmans also requires clearly defining the various roles of project team members. M-Files feature an automated document circulation process, referred to as the "workflow." In this workflow, documents move through a structured workflow designed to ensure quality, consistency, and traceability throughout the approval process. It starts with a planning step, where it is determined which review and approval steps a document needs to go through. Once this is defined, the author is assigned the task of drafting the content.

After the draft is completed, the document goes through two verification rounds. The first round is discipline-specific, where technical reviewers check whether the content aligns with the requirements of their field. The second round takes place at the project level and focuses on the broader context and integration within the project. Any comments made during these reviews are then processed and incorporated by the author.

Once all feedback has been addressed, the document is finalized and converted into a complete PDF, including any required attachments such as drawings, appendices, or cover pages. This version is then checked by the authorizer, who determines whether the document is suitable for internal use. If approved, the document may also receive an internal approval stamp (QR-stempel) and move on to the next step.

The releaser then reviews the document to determine whether it is ready to be shared externally. If approved, the document can be submitted to the client for feedback, verification, or formal acceptance. In case the document is rejected at any stage, it is returned to the rework phase. The author updates the document based on the feedback, after which it re-enters the workflow for another review cycle.

Once the client (OG) receives the document, a coordinator checks whether the published version meets their expectations and contract requirements. If approved, the document can move forward. In some cases, a final check is carried out by the execution manager, who verifies whether the document is ready for use during the execution phase. If the client does not approve the document, it either returns to rework or is reviewed again internally to determine the appropriate next steps. When all reviews are completed and approvals are in place, the workflow is closed, and the document is considered finalized. A schematic overview of this workflow is presented in Figure 6.4

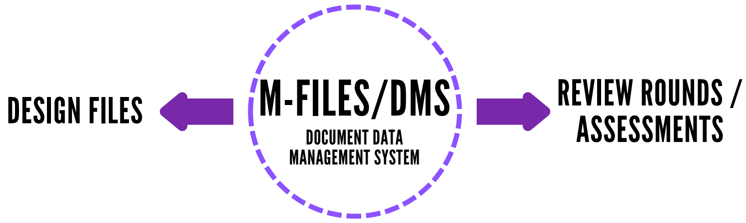



**Figure 6.3:** Data stored in M-files

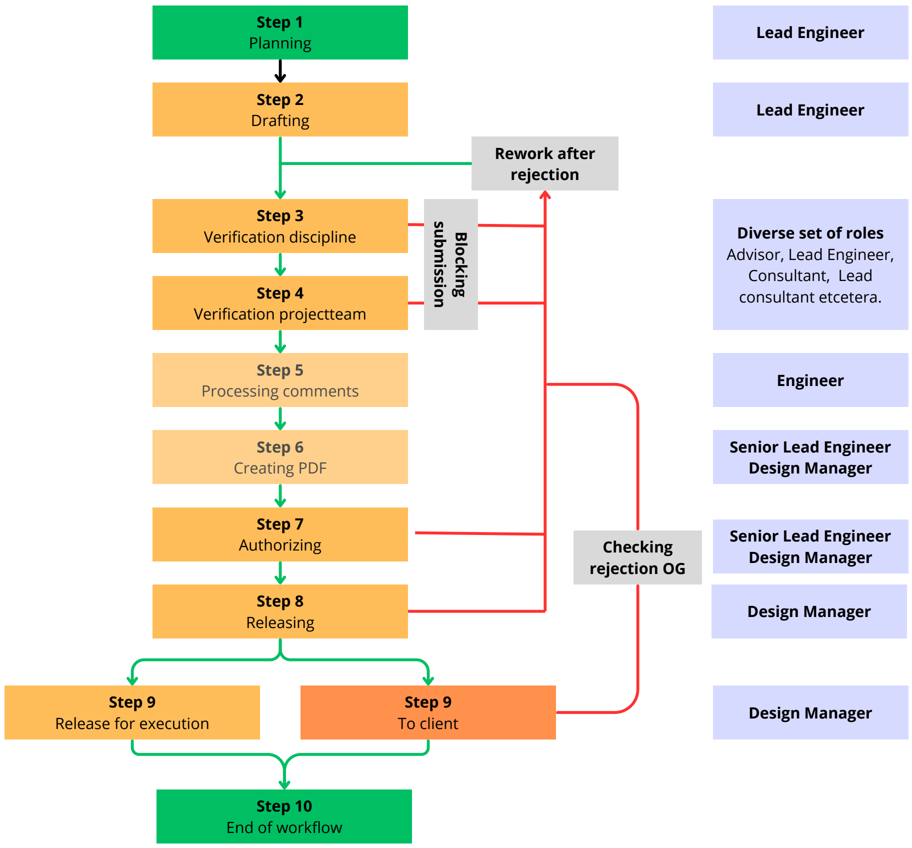



**Figure 6.4:** Workflow within M-files

### 6.2.4. Planning

The focus here is specifically on the planning for the design phase of a project, which is distinct from planning for the execution or construction phases. The design phase planning emphasizes key milestones such as concept development, preliminary design (VO), final design (DO), and detailed design (UO), ensuring that the necessary design deliverables are completed on time. This phase involves activities such as design reviews, approvals, coordination with stakeholders, and iterative design refinements, all of which must be closely monitored and controlled to avoid delays that could affect later stages of the project. One of the tools commonly used for managing design phase schedules is Primavera. Primavera allows for detailed scheduling and tracking of complex projects, enabling project managers to set dependencies, allocate resources, and monitor progress against deadlines. In the context of the design phase, Primavera can be used to create a schedule that includes all design activities, milestones, review periods, and handoffs between different design disciplines.

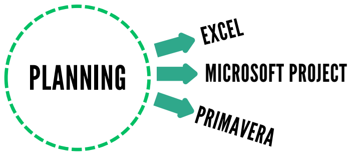



**Figure 6.5:** Different planning systems used

## 6.3. Current processes

After analysing the current data systems and identifying the types of data stored within them, an analysis of the existing process at Heijmans was conducted, taking the case study into account.

### 6.3.1. Design process within Heijmans

For every organization, value is created through the execution of work processes. No matter how complex these processes may appear, they are always composed of actors performing activities with and/or on objects. To provide a clear overview, the Heijmans *'way of working'* is mapped out with the aim of analysing and breaking down work processes in sufficient detail. This enables the identification of actors, activities, and objects at the lowest level of functionality, and provide insight into parts of the design process where inefficiencies can lead to delay.

Within the Heijmans Infrastructure cluster and the scope of this research, the focus will be on the design activities. Within the infrastructure cluster at Heijmans, the concept of a *One Development Scenario* has been introduced. This approach emphasizes streamlining and integrating various processes to enhance efficiency and collaboration. Within this framework, the focus will here be specifically on the design phase, leading to the development of a *One Design Scenario*. This scenario aims to consolidate design efforts into a unified, integrated approach, ensuring that all design activities align with the overarching goals of the One Development Scenario.

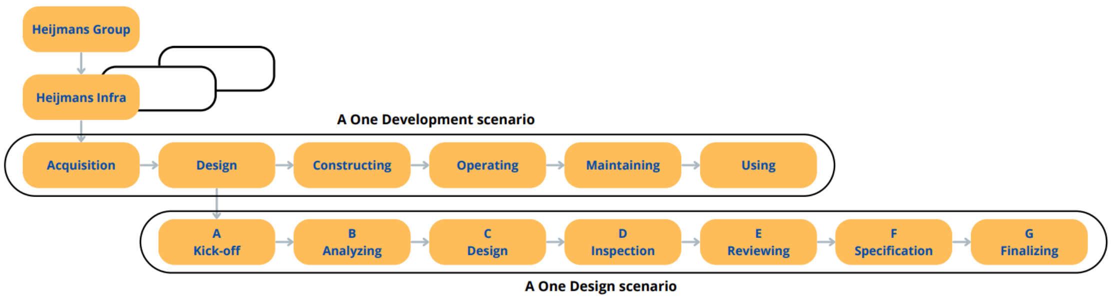



**Figure 6.6:** Heijmans design process

Process descriptions are used to visualize the architecture of business activities. Such descriptions, often depicted in process diagrams, provide insight into the "building blocks" used in a particular process, as well as the operations, relationships, and dependencies required to achieve the intended outcome.

### 6.3.2. Description of the current processes

The approach to track the lifecycle of the component and its associated deliverables shares similarities with creating a business process model. Both methodologies involve mapping the steps required to achieve a specific goals, identifying the dependencies between those steps, and defining roles and responsibilities for each part of the process. In this context, the focus is on the lifecycle of the component, tracking how documents progress through design phases and ensuring their timely delivery at the end of each phase. Based on the literature review, three main design lifecycle phases have been defined: VO, DO, and UO. The completion of those phases are therefore also the most important milestones during the design phase.

#### 6.3.2.1. Heijmans development process

The Heijmans development process is a structured approach designed to execute projects efficiently, cohesively, and result-oriented across all phases. The development process is an integrated working concept where the entire project team collaborates to deliver a feasible, constructible, maintainable, and manageable project. The goal of this is to enhance efficiency, address interfaces more quickly, and improving collaboration. A schematic overview of this process is given in appendix D. The process for the project is divided into five steps:

- **Analysing:** This step within the project is to gain a clear understanding of the task at hand and establish the criteria for determining when the result meets expectations. The output of this step is a verification plan, including verification and validation (V&V) methods, with a validation framework and a baseline document outlining the starting points and assumptions (in Dutch: Uitgangspuntennota)
- **Designing & verifying:** In this step a solution will be definied that adheres to the established parameters and framework from the previous step. This step delivers development notes, drawings, calculations, and a verification report.
- **Controlling:** This step ensures that the design meets the required quality standards and to confirm that each discipline understood each-other. The output of this step is an interface dossier, design approval records (OKR) stored in M-Files and the finalized products, ready for review or implementation.
- **Reviewing:** In this step, the goal is to validate the development process comprehensively at each phase, integrating input from design, realization, asset management, procurement, process management, and stakeholders. The output is a validation framework a external review validation form.
- **Specifying:** The purpose of this step is to determine what is relevant for the next phase. The output is a revised design strategy document and a Go/NoGo decision point to assess readineess for transition to the next phase.

The starting point for tracking the lifecycle of an component is to define the milestones within each design phase. As stated in chapter 3, milestones serve as critical checkpoints that mark the completion of specific tasks or stages in the design process. For each milestone, it is essential to identify and document the deliverables required to achieve it. Once the milestones and their associated deliverables are clearly defined, the next step involves organizing these deliverables by design phase. Based on the analysed case, deliverables typically include feasibility studies, conceptual design drawings, and initial structural calculations. The DO phase requires more detailed deliverables, such as structural analyses, material specifications, and integration plans. In the UO phase, the focus shifts to construction-ready drawings.

This lead to a network diagram which provide useful insights into the design process and which activities/deliverables are crucial for monitoring the design process. To identify potential delays or inefficiencies, document submission dates of deliverables against the milestone deadlines are tracked. This helps to pinpoint bottlenecks and areas where the process may have slowed down. By analysing the progress of each deliverable, including the number of verification rounds and stages they went through (drafting, review, verification, or finalization), the goals is to identify patterns or recurring issues that could have contributed to delays. This overview is given in appendix I

## 6.4. Case study takeaways

The case study highlights several practical challenges, trends, and working methods related to how design processes and data systems are managed in complex infrastructure projects. These insights reflect both strengths and limitations in current practices, and they form the basis for further analysis in the following sections. Below is a summary of the most relevant findings categorized in four categories:

1. **Planning and milestone management**
   The case study revealed several challenges related to the planning and monitoring of design milestones. While milestone deadlines are generally met due to contractual agreements with clients, these submissions are often incomplete. Design packages are regularly delivered without all components being finalized, with the understanding that missing or incorrect elements will be corrected later. This dual interpretation of milestone achievement—meeting the deadline versus fulfilling all deliverables—creates ambiguity in tracking progress. Furthermore, the Primavera planning tool used provides only a high-level overview of activities and lacks the granularity needed to monitor day-to-day document development. Although three key milestones are defined (VO, DO, and UO), there is a lack of SMART criteria specifying what is expected in each design phase. This makes it difficult to objectively assess whether a milestone has been fully achieved.
2. **Data system usage and fragmentation**
   The design management process relies on multiple systems, but these systems are often used in isolation or in a fragmented manner. For instance, the design verification plan is maintained entirely in Excel and requires manual updating, despite verification-related data being available in M-Files. Similarly, a separate Excel-based design schedule outlines responsibilities and allocated hours, but remains disconnected from other planning tools. This decentralized approach leads to inefficiencies and a heavy reliance on manual data handling. Additionally, while M-Files tracks valuable metadata such as version numbers and workflow status, exporting this data for analysis or integration into other tools proves to be difficult. As a result, users are required to perform manual comparisons and data extractions to obtain a complete picture.
3. **System integration**
   Although some system-level connections exist—most notably between M-Files and Relatics via work package linkages—these integrations are limited in scope and functionality. The document workflow stored in M-Files is not dynamically connected to planning data, which is typically kept in Excel or Primavera. As a result, there is no automated way to align planned schedules with document status, requiring teams to manually compare outputs from different systems. This lack of integration introduces risks of misalignment, duplicate work, and inefficiencies. True system interoperability remains a challenge, limiting the potential value of otherwise capable tools.
4. **User experience and workflow practice**
   A recurring issue raised in the case study was the perceived lack of user-friendliness in the available systems. Tools like M-Files, although rich in functionality, are not always intuitive or accessible for quick progress tracking. As a result, project teams often create parallel overviews in Excel to meet their day-to-day information needs. These workarounds highlight a gap between system capabilities and actual team workflows. The analysis underscores that the effectiveness of a digital tool is not solely determined by its technical features, but also by its alignment with user practices and preferences. Without intuitive interfaces and seamless workflow support, even powerful systems are underutilized.

In practice, managing the design process requires more than simply having systems in place. It depends on how these systems are used, connected, and supported by workflows that reflect the complexity of real projects. While M-Files, ACC, and Relatics each play a key role, the case study shows that their full potential isn't always realized. Ultimately, the analysis shows that while the systems in place are capable, their value depends on integration, usability, and alignment with how teams actually work. An effective overview of the design phase can only be achieved when the systems in use are well-integrated and support one another through clear agreements, coherent planning logic, and accessible overviews. Only then can these tools fully support efficient design and milestone management.

# Phase C

## Design & Development

# 7

# Artefact Development

*The artefact developed in this chapter builds upon the foundation laid in the earlier stages of this research, specifically **Phase A** and **Phase B**. In Phase B, the objectives for the solution were defined. Section 7.1 translates these objectives into concrete requirements for the conceptual artefact, based on the findings from the literature review, case study, and interviews. These requirements form the basis for the artefact's design and development in the subsequent sections. Section 7.2 focuses on the design and development of the artefact itself. It outlines the strategies designed to utilize the selected KPIs for improving project monitoring during the design phase. Later on, Section 7.3 will go in on the system architecture, Concluding this section, the proposed artefact guides when and how specific indicators should be applied throughout the different stages of the design process. **From this point forward, the artefact will be referred to as the Design Phase Monitoring Tool (DPMT).***

## 7.1. Objective & requirements

This section presents the input for the conceptual DPMT used in the first evaluation session. The development process follows the steps outlined by Peffers et al. (2007) as part of the Design Science Research Methodology (DSRM). In this methodology, **Phase A** delivers a clearly defined problem statement, while **Phase B** establishes the objectives for a solution. Together, these two phases provide the foundation for identifying requirements that guide the artefact's development. This section aims to determine what kind of artefact could address the identified problem and which requirements are critical to ensure its usefulness, grounded in theoretical insights and practical input from the case study and interviews.

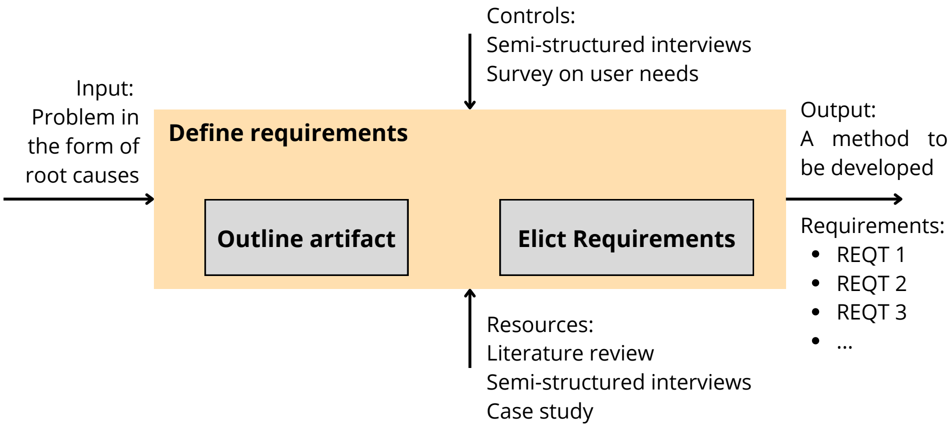



**Figure 7.1:** Method of defining the requirements based on case-study and interview results (based on Johannesson and Perjons, 2014)

### 7.1.1. Outline artefact

The artefact developed is the **Design Phase Monitoring Tool (DPMT)**. Choosing a tool as artefact is driven by the problem relevance and the inefficiencies identified during Phase A and B research. Since the primary goal of this research is to develop and validate a data-driven approach for monitoring the design phase, a tool was needed that enables integration of data sources, supports user-friendly visualizations, and allows iterative refinement based on feedback. However, a tool can't be made without a software program. Therefore, Power BI was selected as a platform to create the tool.

**Choice of PowerBI as the implementation platform**

Power BI was selected as the platform for developing the DPMT, based on a combination of practical, technical, and organizational considerations. First, Heijmans holds a PowerBI license, making the platform widely accessible across the organization. This reduces the barrier for adoption and removes the need for additional training software. Power BI is also well-suited for integrating existing data sources such as M-Files and Relatics. The platform provides robust capabilities for interactive dashboards and customized visualizations, making it possible to present project progress, challenges, and trends in a clear and accessible way.

This function is especially valuable for design managers and leaders, who can use these insights to support their decision-making without requiring further advanced technical expertise to use the platform. Additionally, Power BI supports the iterative approach of this research, enabling the tool to be developed, validated, and refined in stages. Feedback from the users in a focus group can be quickly incorporated into new dashboard versions. Also, PowerBI was selected with a forward-looking perspective: it can be incorporated into Microsoft Fabric, which offers an end-to-end solution for data integration, transformation, analysis, and visualization.

Finally, the widespread use of Power BI in the construction industry aligns with the industry, and therefore, Heijmans' broader digital strategy increases the likelihood that the tool will be adopted in practice and further developed over time.

### 7.1.2. Elicit requirements

To develop the DPMT, it is essential to gather the requirements. These requirements are directly linked to the results of the literature review (Chapter 3, case study (Chapter 6), and interview results. The data gathered in those chapters helped understand the main challenges in tracking the design process and the reasons behind inefficiencies. By addressing these challenges, the DPMT stays practical and works well within the organization's limitations. The requirements are divided into functional, system, and organizational aspects to make it effective and easy to integrate into current workflows. An overview table is provided in Appendix E, where each requirement is described and linked to its corresponding category and to the challenge it addresses: Process & organization related, data & system related, or team related.

**Functional Requirements**

The functional requirements concern the desired capabilities of the tool. The DPMT must integrate multiple existing data systems into a single central overview to monitor progress. In addition, the tool must use standardized design phase milestones and KPIs to measure progress objectively and data-drivenly. It should generate alerts when delays are imminent and present this information in a clear and visual dashboard. Furthermore, the tool must support coordination between design disciplines and automate as many tracking and reporting processes as possible. (Appendix E.1)

**System Requirements**

The structural requirements relate to how the tool should be built and technically embedded in the organization. The tool must be scalable and flexible to accommodate different project sizes, directly connected to existing systems, and based on a standardized data structure to ensure consistency and data reuse. (Appendix E.2)

**Organizational requirements**

Finally, the environmental requirements concern the context in which the tool is used. To ensure successful implementation, the DPMT must align with existing workflows, be user-friendly, and present project information clearly and structured. The tool should not increase workload but instead support and enhance current practices. (Appendix E.3)

## 7.2. Design & Develop

With the monitoring needs and requirements established, this section presents the development of the DPMT. The tool's design was informed by insights gathered during earlier stages of the research—specifically, the literature review, case study, and expert interviews—which served as indirect knowledge sources. No additional interviews were conducted specifically for the development phase.

The DPMT is purposefully designed to enhance situational awareness during the design phase. It integrates data from key project management systems—Relatics, M-Files, and Autodesk Construction Cloud—and translates this information into visualized KPIs aligned with the three levels of situational awareness defined by Endsley: perception (visibility into current project status), comprehension (understanding of progress and bottlenecks), and projection (anticipation of future risks and delays). The dashboard architecture, centered on milestone tracking, document readiness, and verification progress, reflects that actionable insights are essential for informed and timely decision-making. Rather than displaying raw data, the DPMT structures and contextualizes information to enable improved control over the design process.

### 7.2.1. DPMT development

Design processes are often complex and uncertain, especially in the early stages. Rigid, one-size-fits-all planning systems don't always work well in this context. The design phase is often characterized by frequent iterations, limited initial consensus, and continuously evolving insights. Moreover, progress during this phase is frequently assessed based on intuition rather than objective data. Because of this, there's a need for tools that don't just enforce strict control, but instead help teams stay aware of what's happening, making the process more transparent and traceable. This idea guided the development of the DPMT. Rather than focusing purely on deadlines, the tool facilitates a more adaptive planning approach by integrating milestones with KPIs. Previous research by Haponava and Al-Jibouri has demonstrated that using KPIs as a steering mechanism can effectively support such an approach. Milestones act as clear checkpoints in the design process, moments when something important should be completed. KPIs add a layer of insight, showing how efficiently or effectively the design progress is.

The tool's development started with the knowledge platform concept described by Hofstee (2018), which highlights the importance of collecting, storing, and reusing knowledge across projects. This inspired the idea that the DPMT should be grounded in existing project data rather than require new, isolated workflows. At the same time, literature and practice showed that the tool needed to remain flexible enough to work in uncertain design settings.

The development process of the DPMT was divided into three main steps:

1. **Definition of milestones, KPIs, and indicators:** The first step involved defining the milestones, KPIs, and supporting indicators that structure the design phase. These elements were aligned with actual workflows and deliverables used in practice to ensure relevance and applicability within real project environments.
2. **Measurement of KPIs and indicators:** Following the definition phase, attention was directed towards the measurability of each KPI and indicator. This step entailed a detailed examination of how each metric is defined and how it contributes to data-driven tracking of progress throughout the design process.
3. **System architecture:** The final step involves designing a system architecture that integrates the identified KPIs and their corresponding measurement logic into a coherent structure. This architecture defines how data flows from the source systems (e.g., Relatics, M-Files) into the processing environment (Power BI), and how it is transformed into meaningful indicators. The architecture ensures that the developed KPIs can be operationalized practically and scalable, enabling real-time monitoring, consistent computation, and clear visualization within the DPMT.

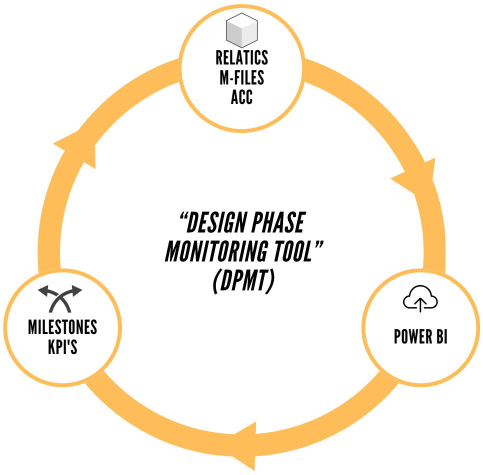



**Figure 7.2:** DPMT knowledge platform

By combining these elements, the DPMT offers more than just a timeline. It gives teams a way to assess whether milestones are being achieved healthily and sustainably. Instead of just asking *"Is the milestone done?"*, the tool encourages teams to ask *"Are we on the right track, and how do we know?"* This shift from static tracking to data-driven awareness helps project teams catch delays earlier, understand performance patterns, and ultimately manage the design process with more confidence and clarity.

### 7.2.2. Definition of milestones, KPIs, and indicators

To make the DPMT functional and meaningful in practice, it is crucial to define which milestones to track and which performance indicators could provide actionable insight along the way. These definitions were based on three inputs:

1. The structure of the design process at Heijmans
2. Data availability from systems like M-Files, Relatics, and ACC
3. Findings from earlier phases of this research

#### 7.2.2.1. Milestone selection

The conceptual milestone framework by Sunmola, (2021) was used to ensure that the selected milestones not only reflect company-specific practices but also align with industry best practices. Literature on project complexity highlights that complex projects, such as those in the design phase of infrastructure development, are often defined by evolving requirements and uncertain methods. In such contexts, setting rigid deadlines is usually ineffective. Instead, creating situational awareness and enabling iterative reviews provides the flexibility needed to adapt as the project progresses (Stacey, 1996; Cicmil et al., 2006; Bosch-Rekveldt et al., 2011).

From the milestone framework by Sunmola, (2021), *four* milestones categories will be used. Each category will address a specific aspect of the design phase. These categories provide structured checkpoints to ensure that project transitions are well-defined, decision-making is timely, and KPIs are there to support tracking.

- **M1 – Completion milestone:** Ensures that the design phase is fully completed, reviewed, and formally approved before transitioning to the next. It reduces the risk of errors, scope ambiguities, and misalignment with project requirements.
- **M2 – Decision milestone:** Introduces predefined decision points to facilitate the timely validation of key design choices. Confirming alignment before advancing helps prevent late-stage changes and minimizes rework.
- **M3 – Management milestone:** Focuses on interdisciplinary coordination, risk control, and compliance. These milestones ensure the necessary checks, reviews, and approvals are in place to support informed and accountable progress.
- **M4 – Soft vs. hard milestone:** Differentiate between internal milestones (used for team-based planning and coordination) and external milestones (contractually binding or tied to external stakeholders). This

distinction supports flexibility while maintaining accountability.

The milestone categories (M1–M4) presented in table 7.1 are derived from a combination of case study findings, interview insights, and supplementary milestones based on the author's understanding. As previously discussed, setting rigid deadlines doesn't align well with the iterative nature of the design process. Instead, building situational awareness throughout the project is far more valuable. To support this, each milestone is linked to a specific moment in the workflow, which connects it directly to measurable data from systems like Relatics and M-Files. This makes it possible to track progress objectively and monitor milestones in real time. Clear definitions are included for each milestone to ensure they are interpreted consistently and can be applied reliably across different projects.

**Table 7.1:** Milestone selection with workflow linkage

| Category | Milestone | Workflow correspondence | Definition |
|---|---|---|---|
| **M1 - Completion milestone** | M1.1 - Completion of VO Phase | Einddatum VVU | The preliminary design is finalized, reviewed, and approved for transition to the next phase. |
| | M1.2 - Completion of DO Phase | Einddatum VVU | The final design is finalized, reviewed, and approved for transition to the next phase. |
| | M1.3 - Completion of UO Phase | Einddatum VVU | The detailed design is finalized, reviewed, and approved for transition to the execution phase. |
| **M2 - Decision milestone** | M2.1 - First Design Cycle (30% Completed) | n/a | The first concept designs for the VO, DO, and UO phases are modeled, covering 30% of the project scope. |
| | M2.2 - Second Design Cycle (60% Completed) | n/a | The second iteration of concept designs for the VO, DO, and UO phases are modeled, covering 60% of the project scope. |
| | M2.3 - Concept of VO Products | Einddatum opstellen | The concept deliverables for the preliminary design have been completed and are prepared for internal review. |
| | M2.4 - Concept of DO Products | Einddatum opstellen | The concept deliverables for the final design have been completed and are prepared for internal review. |
| | M2.5 - Concept of UO Products | Einddatum opstellen | The concept deliverables for the detailed design have been completed and are prepared for internal review. |
| **M3 - Management milestone** | M3.1 - Cross Disciplinary Design Review | n/a | Validation of alignment among the different disciplines for the VO, DO, and UO phases. |
| | M3.2 - Validation of VO, DO, UO Documents | Einddatum verificatie P / einddatum verficiatie D | Completion of all necessary technical and regulatory approvals. |
| **M4 - Soft vs. Hard milestone** | M4.1 - Internal Review (Soft) | Startdatum verificatie P / startdatum verificatie D | Ensuring that design deliverables undergo internal validation before formal submission. |
| | M4.2 - Client Submission Deadline (Hard) | Einddatum vrijgeven | Establishing a final deadline for the external submission of design packages. |

#### 7.2.2.2. KPI selection

Identifying the KPIs emerged directly from the interview results and formed a crucial next step in developing the DPMT. Instead of relying on predefined KPI categories, a bottom-up approach was taken: the content and intent of the indicators themselves guided the formation of the KPI groups. Once the most insightful indicators were identified, they were clustered based on their thematic focus—documentation, requirements, risk, time, or team dynamics. This approach ensures that the KPI groups are firmly grounded in the actual indicators prioritized by experts, and by extension, in the data needed to build situational awareness and support more informed decision-making throughout the design phase.

Table 7.2 provides an overview of the KPIs. The collected data identified five KPI groups as critical for enabling design managers and team leaders to monitor and steer the design process effectively. Each KPI group is supported by a set of relevant indicators and was defined through its contribution to improved decision-making and situational awareness in the project workflow. The table below outlines each KPI group, its title, and a concise description of its purpose.

**Table 7.2:** Overview of Key Performance Indicators (KPIs) used in the DPMT

| KPI Group | Title | Definition |
|---|---|---|
| **KPI 1** | Management of document readiness | This KPI ensures that design documentation is systematically managed, readily available, and accessible throughout the workflow. Effective documentation management supports smooth project execution by minimizing information gaps and delays. |
| **KPI 2** | Management of requirements and changes | This KPI assesses the control and tracking of project requirements and modifications to minimize disruptions and maintain alignment with project goals. A well-structured approach to managing requirements and changes enhances project stability and efficiency. |
| **KPI 3** | Management of risks | This KPI monitors risk identification, mitigation strategies, and stakeholder engagement to ensure project stability. Effective risk management reduces uncertainties and improves decision-making throughout the design phase. |
| **KPI 4** | Management of time tracking | This KPI evaluates time efficiency and workflow performance within the design phase. Tracking time-related metrics allows for process optimization and resource allocation improvements. |
| **KPI 5** | Management of team composition | This KPI examines the structure, flexibility, and adaptability of design teams to ensure efficiency in project execution. Understanding team dynamics enhances collaboration and reduces potential skill gaps. |

### 7.2.2.3. Indicator selection

After defining the KPI groups, the next step is to connect them to specific indicators that can be measured in practice. The selection of indicators is based on the literature review and the findings from this research, ensuring they are theoretically sound and relevant to day-to-day project work. By linking each KPI group to measurable indicators, it becomes possible to track progress more accurately. The selected indicators are aligned with the data already available in systems such as Relatics and M-Files, which makes them practical to apply without needing significant changes to current workflows. While not all indicators are directly supported by literature, those developed from the case study and interviews reflect operational needs observed in practice. For example, the indicators under KPI group 4 are based on the concept of information flow. Table 6.3 shows which indicators are linked to each KPI category, along with a short definition and whether the indicator is supported by existing literature.

**Table 7.3:** Metrics linked to the KPI categories

| KPI group[1] | Indicator | Definition | Found in literature? |
|---|---|---|---|
| **KPI 1** | Number of documents with a certain document status | Monitors the progression of documents through workflow stages (e.g., Draft → Final). | ⚠ Partially (not explicitly listed) |
| | Number of documents in the workflow | Measures the number of documents currently processed in active workflows. | ⊗ Not directly |
| | Documentplanning | Tracks whether documents are submitted on schedule according to milestone deadlines. | ⊗ Not directly |
| | Number of validation rounds | Counts the number of review cycles required before document approval. | ⚠ Indirectly (as rework) |
| **KPI 2** | Number of verified requirements | Tracks the number of project requirements that have been formally verified. | ✓ Yes |

*Continued on next page...*

*Table 7.3 continued from previous page*

| Category | Identified KPIs | Definition | Found in literature? |
|---|---|---|---|
| | Number of open requirements | Monitors the number of unresolved requirements that are still pending verification. | ✓ Yes |
| **KPI 3** | Number of risks provided with mitigation measures | Tracks the number of identified risks with assigned mitigation measures. | ✓ Yes |
| | Number of outstanding risks | Measures the number of unresolved risks at different project milestones. | ✓ Yes |
| **KPI 4** | Verification flow efficiency | Tracks the time required for validation and approval processes. | ⚠ Indirectly |
| | Verification delay | Difference between planned and actual time | ⚠ Indirectly |
| | Average verification processing time | Average time from submission to verification approved | ⚠ Indirectly |

### 7.2.3. KPI and indicator measurement

The input for the DPMT was outlined in the previous section. However, to use the tool, it is essential to understand how each indicator is calculated, which data is needed, and whether any thresholds or benchmarks apply. This section closely examines each indicator, explaining how it is defined and how it supports data-driven tracking during the design phase.

Each indicator was developed using a structured approach that linked practical challenges with measurable data. The indicators used are discussed in the previous section. Those indicators are mapped to available data sources. From there, formulas were created to translate raw data into meaningful insights. To avoid overloading the main report with all indicator explanations, the detailed formulas, eventual flowcharts, thresholds, and data structure for each indicator within each KPI group are given in appendix G. This appendix contains:

1. Definition(s) of each indicator
2. Logic and formulas used for calculation
3. Flowcharts illustrating needed steps
4. Data sources and input structure per indicator
5. Thresholds or interpretive guidance where relevant

Specific indicators build on concepts from information flow theory, which was discussed earlier in the literature review. For example, ideas like flow efficiency and action rate were inspired by earlier work on how information moves through project systems (Tribelsky and Sacks, 2010). These concepts helped ensure the indicators are technically sound and aligned with broader thinking on how data-driven systems can enhance situational awareness in complex environments.

[1]**KPI 5:** *This KPI does not enhance situational awareness during the design phase but offers insight into team-related risks before its start. Additionally, data for the specific metric associated with KPI 5 is not available in the analysed data system. As a result, KPI 5 is not included in the DPMT.*

## 7.3. System architecture

Developing the milestones, KPIs, and indicators alone is insufficient to address the challenges outlined earlier. A more comprehensive solution is required to truly meet the requirements set out in section 7.1.2. As introduced in section 7.1.1, this solution takes shape in the DPMT, developed in PowerBI. The rationale behind using PowerBI for the DPMT is discussed in section 7.1.1. This section explores the proposed system architecture designed to support real-time decision-making and progress tracking throughout the design phase.

**System inputs**

The DPMT combines data from the following two core systems already in use at Heijmans:

- **Relatics** provides information about requirements, including verification status, judgements by verifiers and controllers, and timestamps.
- **M-Files** supplies document workflow data, such as status transitions, version history, submission and approval dates, etc.

Due to system limitations and the scope of this research, retrieving data through automated queries or APIs was impossible. Instead, datasets had to be manually exported in structured formats such as CSV or Excel and transferred into the tool. Sometimes, the data could not be exported and copied directly from the system interface into Excel. Additionally, specific fields were not visible in the main interface but stored in the background layers of the software, which were inaccessible during this research.

As a result, the dataset used in the DPMT consisted of a mix of actual project data and simulated entries, added where information was missing or unavailable. For example, planned delivery dates were not available in the system. These were manually retrieved from project documentation and, where necessary, simulated using ChatGPT. Realistic delivery dates were generated and integrated into the dataset by providing the model with document names and corresponding time ranges.

A similar method was used to fill in missing judgment values for design requirements. The valid values were “Voldoet,” “Voldoet niet,” or “Geen oordeel.” A prompt was designed to simulate these fields, allowing ChatGPT to learn from the patterns already present in the dataset. The logic followed a few simple rules: if a requirement had no open issues, the judgment was likely ”Voldoet”; if open requirements were present and accompanied by a note, the judgment would be ”Voldoet niet”; and if open issues were listed without additional comments, ”Geen oordeel” was most appropriate.

The prompt used is shown below:

> *I have a dataset of design requirements where some entries have missing judgment values. The valid judgments are:*
>
> - *"Voldoet"*
> - *"Voldoet niet"*
> - *"Geen oordeel"*
>
> *Many other entries do have these values filled in. Can you analyse the patterns in the existing data, including fields like the number of open requirements, whether notes are present, and any other relevant columns, and then simulate realistic values for the missing judgments accordingly?*
>
> ***Key logic:***
>
> - *If the number of open requirements is 0, the judgment is likely "Voldoet".*
> - *If there are open requirements with notes, it should be "Voldoet niet".*
> - *If open requirements are without notes, it is likely "Geen oordeel".*
>
> *Please learn from the structure and frequency of existing entries in the dataset and use that to fill in the missing ones.*

Although this introduced a few extra manual steps, it allowed for more control over data quality. It ensured that the dataset remained traceable and transparent throughout the tool’s development and testing.

**Internal logic and calculations**
Once data is gathered, Power BI is used as the main environment for structuring and computing key indicators. The internal logic is organized around the KPI framework defined in section 7.2.2, with each KPI supported by a clear formula and condition. Key steps in the calculation logic include:

- **Data mapping:** Document IDs, requirement IDs, and component codes are used to connect datasets from different systems.
- **Formula-based computation:** KPIs such as verification rates, workflow re-entries, and average processing times are calculated using DAX (Data Analysis Expressions) within Power BI. These formulas replicate the logic of traditional Excel functions (e.g., COUNTIFS, SUMIFS, MAXIFS) but are adapted for dynamic data modeling.
- **Time-series structuring:** Indicators like action rates and document status distributions are computed weekly to enable performance tracking across time.
- **Threshold checks:** Each KPI was, where possible, compared to a predefined threshold using DAX logic. Results are categorized into green, yellow, or red flags to signal emerging risks or performance concerns.
- **Model structure and tables:** All supporting calculations, intermediate columns, and visual mappings are created within Power BI.

**Data flow**
Figure 7.3 illustrates the current manual architecture used in this research, alongside a proposed automated setup. The implemented architecture (left) relies on manual data extraction from Relatics and M-Files, transferred via Excel into Power BI. While Excel acts purely as a data transfer medium, all data cleaning, transformation, and analysis occur in Power BI.

The processed data is then visualized through interactive dashboards, which allow users to:

1. Monitor design KPIs in real time.
2. Search project-specific data.
3. Identify trends and deviations from benchmarks.

Although this approach delivers valuable insights and improves visibility into the design process, its reliance on manual data updates limits the tool's ability to support fully real-time decision-making. The proposed architecture addresses this by introducing a centralized database with automated data extraction across systems, which enables continuous data flow, feedback loops, and enhanced project monitoring capabilities. For the used system structure, see appendix K.

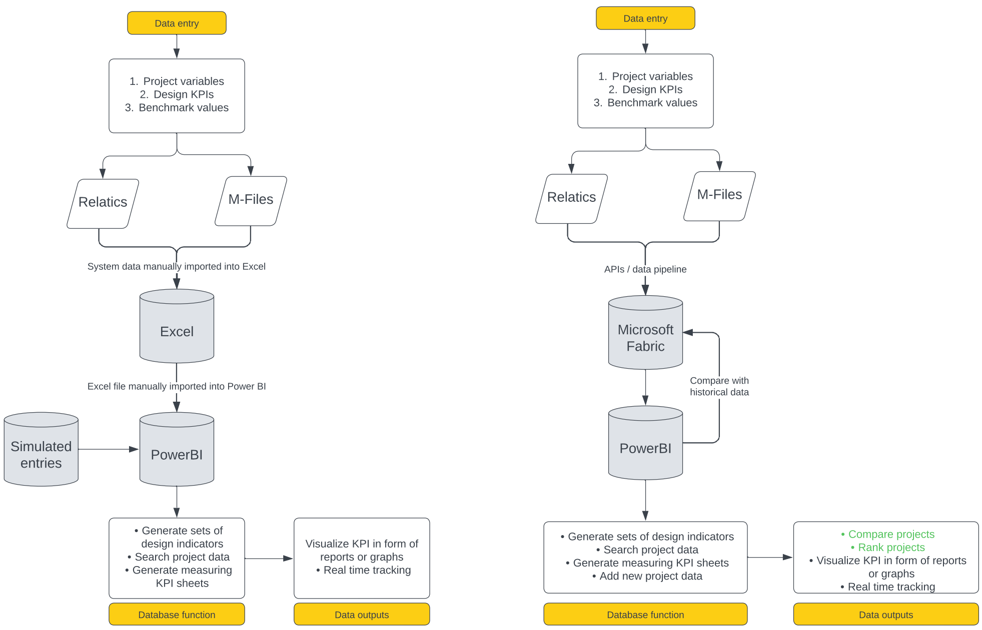



**Figure 7.3:** Used system architecture (left), proposed system architecture (right)

# Phase D

## Demonstration

# 8
# DPMT Demonstration

*This chapter presents a proof-of-concept demonstration of the Design Phase Monitoring Tool (DPMT), using real project data from a Heijmans infrastructure project. The aim is to showcase the tool's intended functionality and illustrate how it could enhance milestone visibility, situational awareness, and decision-making. Although the tool is not yet implemented or validated within a live project environment, this simulated application demonstrates its potential value and integration within existing workflows.*

## 8.1. Demonstration of the DPMT

With all key elements in place, the DPMT has been constructed. This section presents a demonstration of the tool as used during the first evaluation session. In addition to showcasing its functionality, this demonstration also provides the basis for answering the following sub-question:

> *"How can construction companies leverage the tool to enhance control over milestones and reduce the risk of delay?"*

The outcome of this step will consist of both descriptive and explanatory knowledge. It will illustrate how the DPMT functions and explain why it works. While the demonstration may not fully guarantee performance in all situations due to varying project scopes, it can indicate the potential for broader applicability. Furthermore, demonstrating the DPMT helps communicate its purpose and functionality to users more effectively.

### 8.1.1. Project selection & scope of demonstration

To demonstrate the DPMT, data from a Heijmans project was used, focusing on one single component covering the VO and DO phases. This component was chosen because it offers a representative example of the challenges encountered in the design phase: a moderate yet diverse set of documents, verifications, and workflow activities. These characteristics make it a suitable and sufficiently complex use case to serve as a test bed for evaluating the DPMT's capabilities. Further, the project aligns with this research's earlier defined scope.

Although limited to a single component, this setup reflects broader project structures at Heijmans. It allows for a focused demonstration of the tool's functions under real-world conditions, including system limitations and data inconsistencies. The demonstration tests selected parts of the DPMT, based on the availability and completeness of data. The demonstration, therefore, focuses on the four KPI groups defined in Section 7.2.2, with the following scope:

1. **KPI Group 1: Management of Document Readiness** – *Fully implemented.* This group includes indicators related to document workflows, status transitions, and availability. Based on data from M-Files, the DPMT tracks document progress through various workflow stages and visualizes readiness metrics over time.
2. **KPI Group 2: Management of Requirements and Changes** – *Fully implemented.* Using data from Relatics, this group measures verification progress, judgment outcomes, and change tracking across requirements.
3. **KPI Group 3: Management of Risks** – *Not implemented.* This group was excluded from the analysis because the relevant risk-related data could not be exported to Excel or CSV or retrieved manually. Access

to this information would require implementing the system architecture proposed earlier, which falls outside the scope of this research.

4. **KPI Group 4: Management of Time Tracking** – *Partially implemented.* While some time-related indicators—such as average processing time between workflow stages—could be derived from M-Files data, other planned metrics (e.g., cycle time per requirement, idle time between activities) could not be developed due to missing timestamps and incomplete process logging.

This demonstration highlights the functional core of the DPMT by showcasing KPI Groups 1 and 2 while also revealing current limitations in data availability that hindered the implementation of Groups 3 and 4. These findings provide insight into both the prototype's strengths and the key priorities for future development.

[0] *The demonstration of the DPMT serves as a proof of concept, illustrating how the tool can integrate data from various systems to enhance situational awareness during the design phase. The purpose of this demonstration is not to conclude an ongoing project, but rather to show how the DPMT functions in practice and the type of insights it can generate when applied to real project data.*

### 8.1.2. DPMT-Filter menu

The DPMT's filter menu allows users to interactively navigate through the project data and focus on specific components, documents, or phases. It enhances the tool's usability by offering targeted views based on user needs. Each filter is described below.

**WBS (Work Breakdown Structure)**
This filter enables users to select a specific work package or project component. For example, "04.02 Ontwerpen" refers to the design work for a particular subsystem. Selecting a WBS narrows the data scope to that part of the project. All the data from the different datasets will be filtered based on the input selected here.

**SBS (System Breakdown Structure)**
The SBS filter allows for filtering physical objects or subsystems, such as bicycle underpasses or bridge components (e.g., "03.01 – KW1. Graafseweg"). This is particularly useful for analysing design progress at the object level.

**Ontwerpfase**
This filter lets users choose the design phase they want to view: Voorontwerp (VO), Definitief Ontwerp (DO), or Uitvoeringsontwerp (UO). Since each phase has different deliverables and milestones, this filter helps isolate relevant information for that specific phase.

**Documentnaam**
Users can select individual design documents (e.g., drawings or technical calculations) with this filter. It provides a focused view of the chosen documents' status, revisions, and workflow history. It shows only documents that comply with the filters set above.

**Ontwerpperiode**
This date range selector defines the period of interest within the design process. It allows weekly tracking of progress.

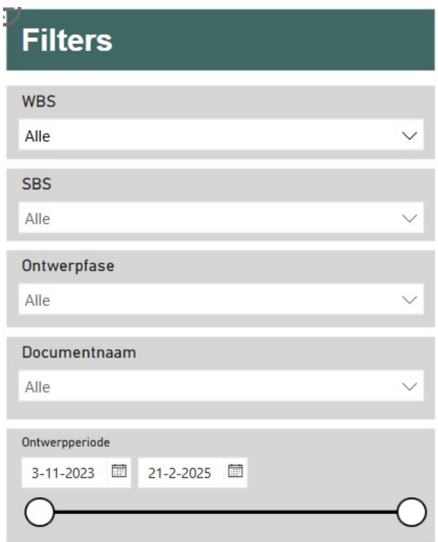



**Figure 8.1:** Filter menu of the DPMT

### 8.1.3. DPMT - Milestones

The milestone overview sheet gives a clear summary of important deadlines and events during the design phase. It includes milestones for each main design stage (VO, DO, and UO) and shows how many days are left until each one. This helps project teams quickly see what's coming up and where their focus should be. This part of the tool is not connected to a planning system. That means all dates and countdowns were entered manually, and the overview won't automatically update if something in the project planning changes. Even though it's not dynamic yet, the sheet shows how useful it can be to bring all milestones together in one place. It helps create a better overview of what needs to happen and when—something often missing in current design processes.

### 8.1.4. DPMT - KPI group 1

The KPI 1 group dashboard sheet increases situational awareness by providing a real-time visual overview of document progress, workflow efficiency, document statuses, and review patterns. Figure 8.2 shows a part of the DPMT - KPI 1 dashboard. The left-hand graph illustrates how document output changes throughout the project by displaying the cumulative number of completed documents over time. Two gauge indications on the right-hand side compare the number of completed documents for the VO and DO phases to the anticipated number.

Eight documents were prepared and finished for VO, demonstrating 100% adherence to the documentation strategy. On the other hand, 32 documents have been submitted for the DO phase, compared to 18 that were planned. This indicates that some documents have been submitted more than once, which may indicate quality problems or client modifications made after the document was submitted.

Below these metrics, the workflow efficiency score and repeat rate offer information about the process's stability and quality. The VO phase's process repetition rate is 37.5%, which indicates that three of the eigh documents needed rework or were rejected internally. Remarkably, at 0.80, the workflow efficiency score for the same phase is still comparatively good. The fact that these rework cycles took place *before* the documents were sent to the client (OG) explains why this can appear inconsistent. As a result, even after multiple internal revisions, each document was only finalized once. Despite prior problems, the efficiency score may be inflated since these documents are counted as having only needed one successful cycle in the efficiency calculation. This emphasizes the importance of evaluating several KPI 1 indications together because efficiency and repetition rate each represent distinct facets of workflow quality and process performance.

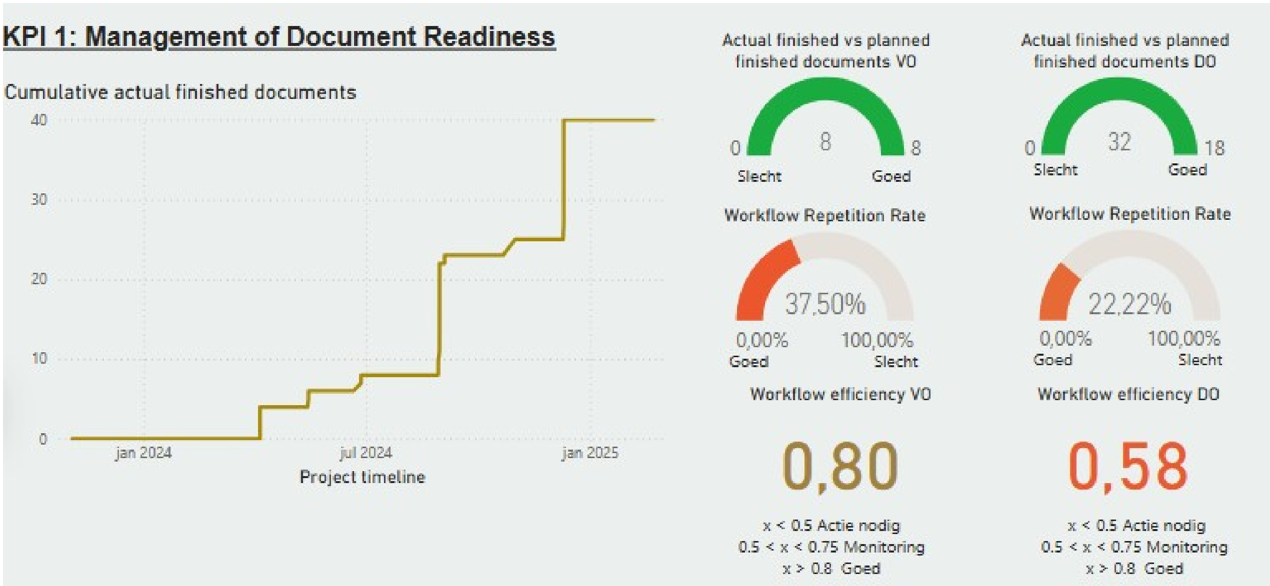



**Figure 8.2:** DPMT - KPI 1: Document-planning and number of validation rounds

Figure 8.3 displays the action rate for documents in the workflow. The graph on the left presents a 5-day rolling average of workflow actions plotted over the project timeline. Peaks in February and April indicate concentrated bursts of workflow activity, likely associated with internal deadlines or milestone preparation. In contrast, extended periods of low or near-zero activity suggest stagnation in document handling. A low action rate may also indicate that documents remain in the same workflow status for a prolonged period without progress. This could point to delays in verification, a lack of assigned reviewers, or general inactivity in the design or review process.

Ideally, the target value for this KPI would be established based on historical workflow activity from previous projects. Such a benchmark would allow teams to assess whether current activity levels align with expected performance.


**Figure 8.3:** Action Rate for documents in the workflow

Figure 8.4 visualizes the distribution and evolution of document statuses over time. On the left, a donut chart shows the current status of all documents within the filtered scope. In this example, the distribution is balanced, with 25% of documents in each of the following statuses: Concept in bewerking (Draft in progress), Concept ter autorisatie (Draft for authorization), Concept ter verificatie (Draft for verification), and Definitief (Finalized). This snapshot provides immediate insight into the overall progress of documentation, revealing whether the design team is primarily still developing documents or has advanced toward approval and finalization.

The center bar chart presents a weekly timeline of document status changes. It indicates when documents transition between workflow stages, broken down by status and color-coded accordingly. Ideally, the dashboard would show the exact status of each document every week, providing a continuous overview of progress. However, due to limitations in the available data, only the timestamps of status changes could be extracted. As a result, the chart reflects transition events rather than persistent weekly status. Despite this constraint, the visualization still offers valuable insights into the momentum and distribution of document workflows across the design period.

On the right, a cumulative indicator displays the total number of document status changes across the entire design period: 186. This reflects the total volume of workflow activity and helps assess whether the team is actively managing documentation continuously or relying on periodic push efforts.

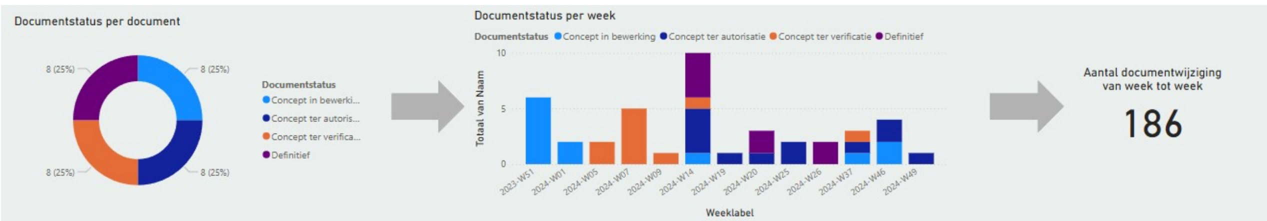



**Figure 8.4:** Distribution of document statuses

[0]*For the full KPI 1 sheet, see appendix L*

### 8.1.5. DPMT - KPI group 2

KPI group 2 monitors the progress and quality of requirement verification and authorization throughout the design process. It focuses on whether requirements have been assessed, by whom, and whether they meet the targets for each design phase. This section demonstrates how the KPI helps identify risks and workload imbalances using data from the VO and DO phases of the underpass component.

Using the filter menu, the analysis was narrowed to the relevant work package (WBS 04.02 Ontwerpen), object (SBS 03.01), and period (2 February to 28 October 2024). The dashboard then displays key indicators: *the number of verified and open requirements, progress over time, and performance per verifier or controller.*

In the VO phase, 72 out of 73 planned requirements have been verified, resulting in 98.6% completion and minimal remaining workload. In contrast, the DO phase shows a clear delay: only 54 of 119 requirements have been verified (45.4%), and 65 remain open. This backlog represents a risk to timely design validation and milestone achievement.

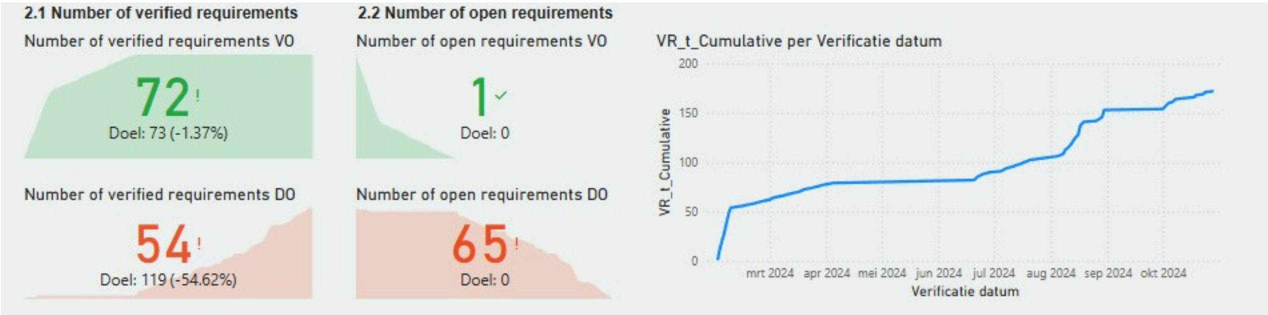



**Figure 8.5:** Overall progress of VO and DO phase

In addition to monitoring overall progress, the DPMT allows for monitoring verification progress at the individual document level.

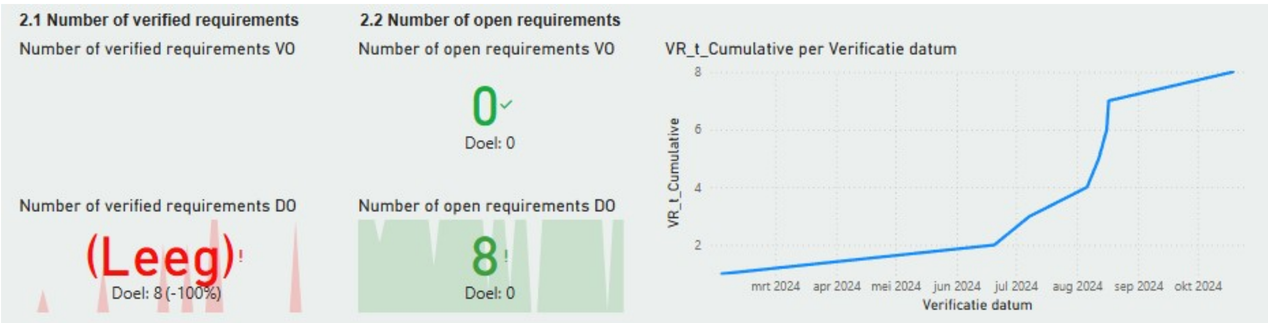



**Figure 8.6:** Progress focus on one single document

Additionally, a time-series graph shows the cumulative number of verified requirements over the design period. These trends help evaluate whether verification activity is steady or stagnating, enabling proactive intervention. Weekly tracking further supports early risk identification by linking verification progress to project timelines and planned dates in M-Files.

Figure 6.8 and Figure 6.9 present a detailed view of requirement verification progress, broken down per individual verifier and controller. These figures demonstrate how the DPMT enables monitoring not only at the overall project level but also at the personal level, making workload distribution and progress transparent.

The dashboard also reveals a significant imbalance in workload. One verifier is responsible for 94 requirements, while others have 12 or fewer. This uneven distribution may create bottlenecks, especially when the verification deadline approaches. Visualization of this data makes it easy to identify which team members are overburdened and where coordination efforts may be needed.

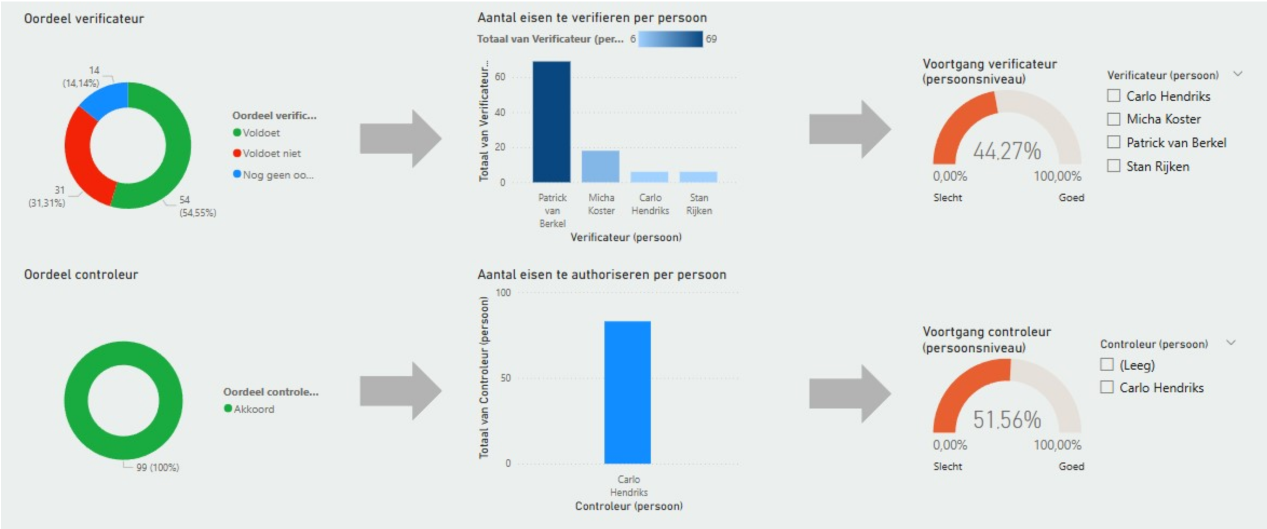



**Figure 8.7:** Detailed overall view of requirements

The dashboard provides an overview of the entire VO or DO design phase and enables visualization at the document level. This granular view allows one to identify bottlenecks related to specific documents, assess where work pressure is currently concentrated or may arise, and observe which individuals are responsible for verification and control. It also highlights whether certain team members are falling behind in their verification tasks relative to approaching deadlines, supporting timely intervention.

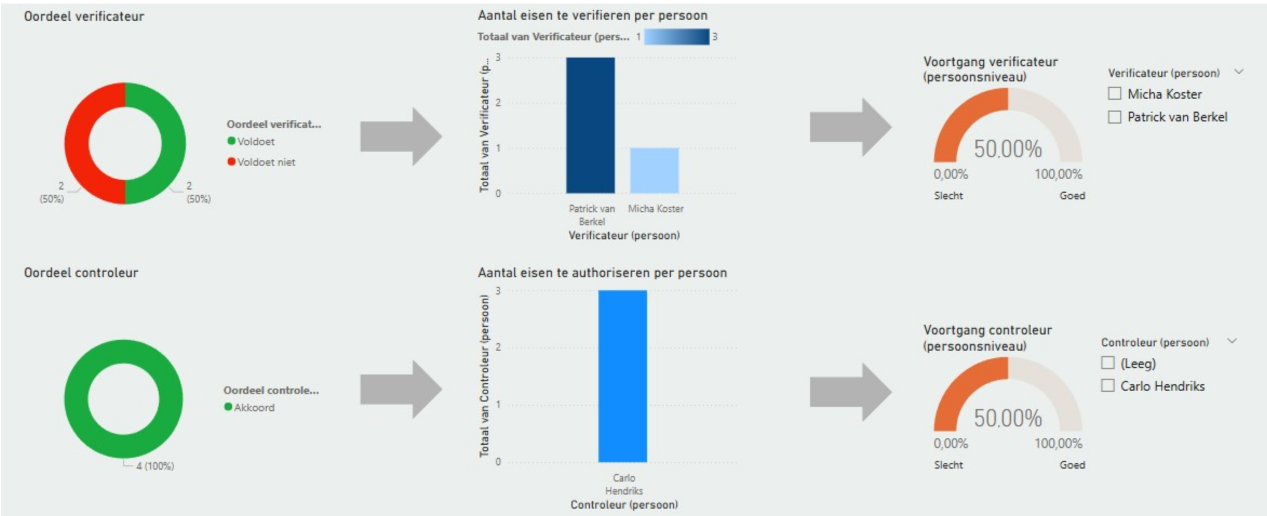



**Figure 8.8:** Detailed view of requirements on document level

0 *For the full KPI 2 sheet, see appendix L*

### 8.1.6. DPMT - KPI group 4

The demonstration of KPI 4 focused on the VO and DO documents of the underpass component and aimed to provide insight into the timeliness of verification activities. Two key indicators were implemented: the Verification Delay (VD) count and the Average Verification Processing Time (AVPT). The VD indicator shows how many documents were verified either early (16), on time (1), or late (23), based on a comparison between the planned verification date and the actual timestamp of verification. This immediately shows whether verification is being managed effectively and where potential risks to the milestone schedule might be forming.

The AVPT indicator offers further perspective by comparing the average expected time to complete a verification with the actual measured average. In this case, the planned AVPT was 6.93 days, while the exact processing time reached 25.28 days, over three times longer than anticipated. A separate trend graph shows how this gap has evolved, making it easier to identify whether the situation is improving, stabilizing, or worsening. These time-based insights help uncover inefficiencies in the review process that are often not visible in standard progress reports.

While it was impossible to implement all desired time-related indicators, such as idle time between workflow transitions or total cycle time per requirement, due to limitations in the underlying data, the prototype already demonstrates the value of even basic timing metrics. KPI 4 shifts the focus from simply tracking deliverables to understanding how quickly processes are moving, and whether that speed is sufficient. This makes it easier for project teams to spot delays early, assess where time is being lost, and take action before problems escalate. In doing so, KPI 4 is key in improving situational awareness and strengthens the DPMT's role as a practical decision-support tool.


**Figure 8.9:** Indicators related to KPI group 4

[0] *For the full KPI 4 sheet, see appendix L*

# Phase E

## Evaluation

# 9
# DPMT Evaluation

*This chapter evaluates the DPMT through a focus group session with six design managers from Heijmans. Based on user feedback and expert insights, the evaluation assesses the tool's feasibility, practicality, and applicability. In addition to identifying strengths and areas for improvement, the insights gathered during this session directly informed the refinement and development of the final version of the DPMT.*

## 9.1. Validation of the DPMT

After demonstrating the DPMT, the next step is to validate the tool. To do this, a focus group session was held with experts from Heijmans. The main goal of this session was to explore how feasible, practical, and applicable the DPMT is. By discussing the tool with experts, the validation goal is to gather valuable feedback that can help fine-tune the DPMT and ensure it fits well with the day-to-day realities and needs of the organization. This section presents the results of the validation. It begins by discussing the strengths of the DPMT, followed by the identified areas for improvement and points for attention. Finally, the strengths and improvement points are brought together in a summary table, outlining potential next steps for further development and implementation of the tool.

### 9.1.1. Focus group procedure

The focus group session was conducted with consent from all participants. It presented the research findings, specifically the conceptual DPMT, developed in this research. The session was organized around a step-by-step PowerPoint presentation to ensure structured and meaningful engagement.

Participants were first shown a demonstration of the DPMT using example data. Following the demonstration, they were invited to share their observations through sticky notes and group discussions. The questions focused on several key aspects: the relevance of the presented indicators (KPIs) for monitoring progress, the clarity and user-friendliness of the dashboard interface, and the tool's compatibility with existing processes and systems. This setup encouraged participants to identify both strengths and areas for improvement.

### 9.1.2. Strengths of the DPMT

The discussion revealed several strengths of the DPMT. Participants indicated that the tool, as presented, offers significant value for monitoring the design phase in different ways. This directly aligns with restoring situational awareness. Design teams were, for the first time, able to perceive ongoing progress and comprehend bottlenecks such as verification delays and upcoming project issues that might lead to missed milestones. This practical feedback confirms that the tool supports all three levels of situational awareness and validates its role as more than just a visual reporting tool—it enables more informed and anticipatory decision-making.

**Clarity and overview**

All participants acknowledged that the DPMT provides a clear, visual dashboard that offers a comprehensive overview of the design process. The combined presentation of different data types (e.g., document status, requirements, verification processes) in a single dashboard was considered highly insightful. One participant noted that *"this shows everything you would otherwise have to piece together manually across systems"*. At the same time, another described it as *"the missing piece that ties it all together."* . Participants also noted that tools for monitoring the design phase are still often developed in Excel, which can be time-consuming and difficult to maintain. They emphasized that this dashboard can potentially replace such manual, spreadsheet-based approaches. As one participant remarked, *"having this at a glance gives us the overview that we need during the design phase.*

**KPIs and indicators:**
Participants were explicitly asked to assess the usefulness of the KPIs and indicators incorporated into the DPMT as part of the focus group evaluation. The feedback confirmed that the selected indicators were highly relevant and aligned with practical information needs. In particular, indicators such as the number of verified requirements, the status of document approvals, and the frequency of repeated workflow entries were recognized as valuable for monitoring progress and identifying inefficiencies. Participants noted that these indicators reflected familiar challenges in design coordination, including rework, delays in verification, and limited visibility across disciplines.

A key strength highlighted by the group was the ability to connect different data types—such as linking requirement verification directly to document status—within a single dashboard. This integrative functionality, which draws on data from systems like Relatics and M-Files, was seen as instrumental in improving situational awareness.

**Ease of use**
Participants assessed the dashboard as intuitive and visually appealing. The filter possibilities and recognizable navigation elements made the tool easy to use. As one participant explained: *"This is so much easier than scrolling through Excel sheets or pulling data from three different places.*"Several highlighted that the clarity of titles and graphs reduced the chance of misinterpretation. *"You don't need to guess what something means, it's right there in front of you,*" was one of the comments regarding visual readability.

**Potential for integration with existing systems**
Although the current version relies on manually exported data, participants saw strong potential for integration with live systems. The fact that the DPMT is built in Power BI was seen as a major advantage. One participant emphasized: *"If this could update automatically from Relatics and M-Files, it would save so much time, we wouldn't need our own separate dashboards anymore.*" Another added: *"It's great that this could be rolled out as a reusable template across different projects.*"

**Support and relevance in practice:**
Perhaps most importantly, the session revealed broad support for the tool. One design manager stated: "I need this on every project, this should be standard." Participants consistently pointed to the lack of such an overview in current practice. "Relatics has the data, M-Files has the documents, but there's no place where it all comes together like this," one participant noted. This feedback reinforces that the tool addresses a clear and pressing need within the organization.

### 9.1.3. Improvements of the DPMT

In addition to the strengths, the validation session revealed several improvement points and areas for further development. Participants identified aspects in which the current version of the DPMT is limited or could benefit from enhancement:

**Lack of automated data integration:**
Participants acknowledged that manually exporting data from Relatics and M-Files is a logical first step in developing the DPMT. Given the tool's prototype status, this approach allowed for rapid testing and flexibility in shaping the dashboard's structure. However, several participants emphasized that automated data integration will be essential for the DPMT to be genuinely effective in daily project management. Without live data connections, the risk remains that outdated information may be presented, potentially reducing trust in the dashboard's accuracy. Further research is therefore needed to explore how these integrations can be realized in a secure, sustainable, and scalable way.

**No dynamic milestone dates:**
Closely related to the above, the tool does not yet support dynamic updates of milestone dates based on changes in the project schedule. The milestone dates (e.g., VO, DO, UO) were static examples in the demonstration. As one participant commented: *"If the planning shifts and the dashboard doesn't reflect that automatically, you still need to go in and adjust things manually"*. The dashboard cannot adapt to real-time deadline shifts

without integration with planning tools.

**Limited predictive capability:**
The DPMT currently serves mainly as a monitoring instrument and lacks predictive analytics. Participants recognized this limitation and suggested it as a key direction for future iterations. One attendee remarked: *"It would be great if this could warn me, not just show what already happened or is happening."* Another proposed: *"If you have all this historical data, couldn't you use it to see which documents tend to get stuck?"*. While predictive features were outside the scope of the initial version, the feedback emphasized the value of integrating basic trend analysis or alert systems to flag risks before they materialize.

**No integration with interfaces, review comments, or geospatial data:**
The most important feedback was that the current scope of the DPMT focuses on document and requirement progress, but does not include data such as open interfaces (raakvlakken) and unresolved review comments. This was seen as a gap by participants. One participant pointed out:*"You might see a document marked as 'ready,' but if it still has 20 unresolved comments, it's not really ready."* Another added: *"We have hundreds of raakvlakken open on this document, why not show those too?"* Therefore, participants suggested incorporating indicators linked to review comment status or open interfaces to improve the assessment of document readiness.

Additionally, spatial visualization (GIS) was mentioned as a future enhancement: *"It would be interesting to combine this with location data, then you can see which areas of the project are falling behind."* These dimensions were considered critical for capturing the complete picture of design progress and quality.

**Unclear interpretation of certain KPIs:**
Some indicators, particularly "workflow efficiency" and "action rate," were not immediately apparent to participants. These indicators were new concepts to some and lacked an intuitive explanation. One participant noted: *"I see a graph with percentages, but I don't know what's good or bad, what does 80% efficiency even mean?"* Another asked: *"Action rate, does that mean the document is active, or that it's delayed?"* These comments underline the need for more precise terminology and possibly in, dashboard definitions or tooltips to ensure consistent interpretation.

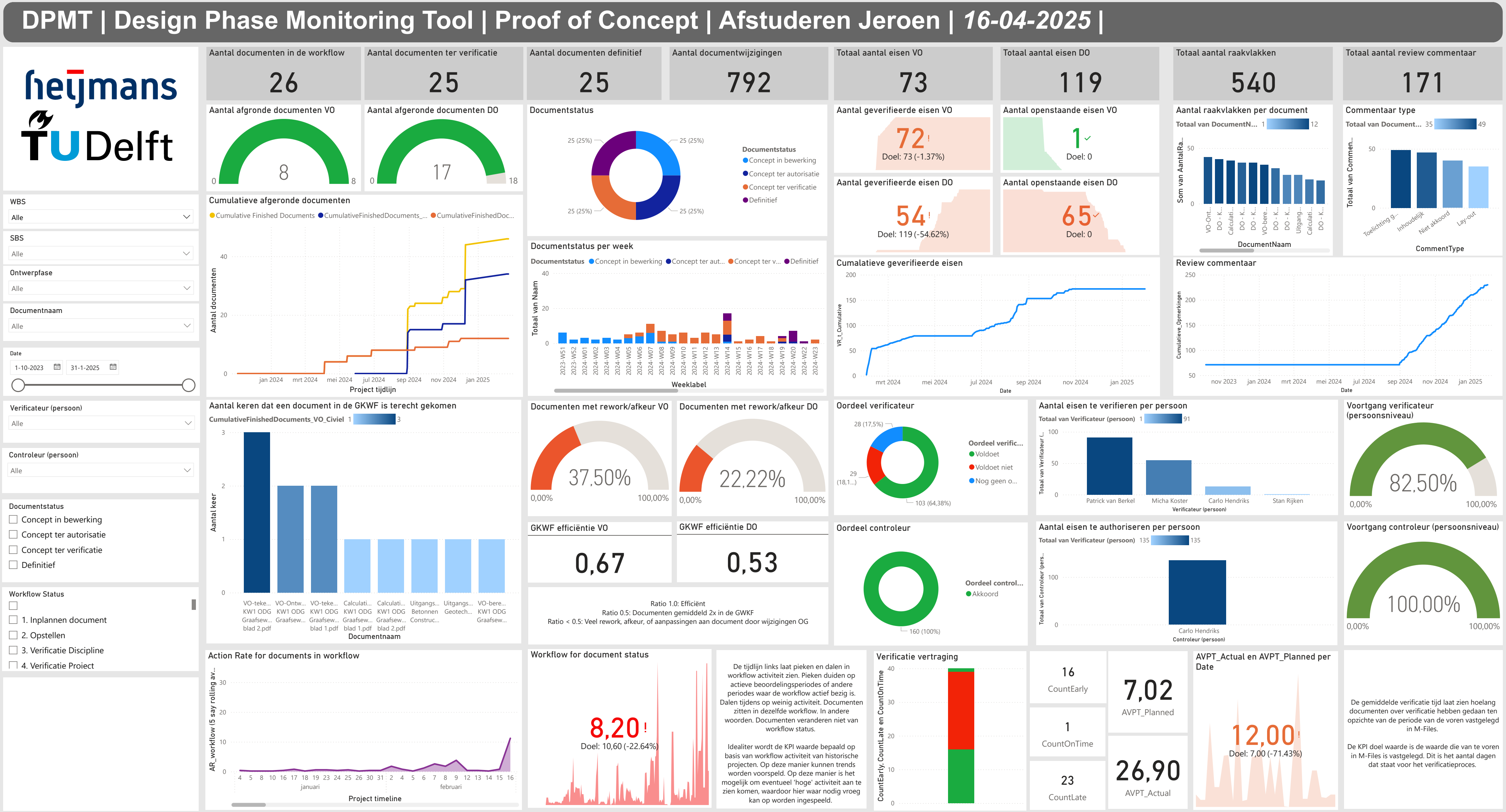
## 9.2. Final DPMT

Based on the extra insights from the focus group session, the final stage of this research involved creating an improved version of the DPMT. The conceptual DPMT was split across three separate sheets, each working with its dataset, and the final version brings everything together. All datasets are connected, which means that it is possible to directly connect data from M-Files and Relatics, which, therefore, gives, for example, direct insight into document status vs. requirements status.

Most of the visuals from the earlier version have been kept to ensure continuity, but several significant improvements were made based on feedback. For example, a text box was added to the Action Rate visual to clarify how it should be read and explain that this KPI's target value should ideally be based on historical project data instead of a fixed number. The same goes for the average validation time. It is now shown for just one component as a demonstration, but this value is not yet representative. In practice, this metric would also benefit from being grounded in real project data.

Another addition to the final dashboard includes indicators for the number of issues and review comments per document. Although this data wasn't available from either M-Files or Relatics during the research, it was simulated to show how it could contribute to better document tracking and situational awareness. This idea came directly from the validation session, where participants expressed a need for more insight into the actual content and quality of design deliverables.

The focus group also highlighted both strengths and areas for improvement. The DPMT was generally seen as user-friendly and relevant, helping to make ongoing activities in the design phase more visible. At the same time, the feedback pointed out that some features, like milestone dates, are still static, and the dashboard doesn't yet have predictive capabilities or automated data integration. While those things are outside the scope of this research, the final version of the DPMT was built with these future needs in mind, keeping the structure flexible and ready for further development.


DPMT | Design Phase Monitoring Tool | Proof of Concept | Afstuderen Jeroen | 16-04-2025 |
heijmans
TU Delft
Aantal documenten in de workflow
26
Aantal documenten ter verificatie
25
Aantal documenten definitief
25
Aantal documentwijzigingen
792
Totaal aantal eisen VO
73
Totaal aantal eisen DO
119
Totaal aantal raakvlakken
540
Totaal aantal review commentaar
171
Aantal afgronde documenten VO
8
Aantal afgeronde documenten DO
17
Documentstatus
Concept in bewerking
Concept ter autorisatie
Concept ter verificatie
Definitief
Aantal geverifieerde eisen VO
72
Doel: 73 (-1.37%)
Aantal openstaande eisen VO
1
Doel: 0
Aantal geverifieerde eisen DO
54
Doel: 119 (-54.62%)
Aantal openstaande eisen DO
65
Doel: 0
Aantal raakvlakken per document
Commentaar type
WBS
Alle
SBS
Alle
Ontwerpfase
Alle
Documentnaam
Alle
Date
1-10-2023
31-1-2025
Cumulatieve afgeronde documenten
Project tijdlijn
Aantal documenten
Documentstatus per week
Weeklabel
Totaal van Naam
Cumalatieve geverifieerde eisen
Review commentaar
Verificateur (persoon)
Alle
Controleur (persoon)
Alle
Aantal keren dat een document in de GKWF is terecht gekomen
Aantal keer
Documentnaam
Documenten met rework/afkeur VO
37,50%
Documenten met rework/afkeur DO
22,22%
GKWF efficiëntie VO
0,67
GKWF efficiëntie DO
0,53
Ratio 1.0: Efficiënt
Ratio 0.5: Documenten gemiddeld 2x in de GKWF
Ratio < 0.5: Veel rework, afkeur, of aanpassingen aan document door wijzigingen OG
Oordeel verificateur
Voldoet
Voldoet niet
Nog geen o...
Aantal eisen te verifieren per persoon
Patrick van Berkel
Micha Koster
Carlo Hendriks
Stan Rijken
Voortgang verificateur (persoonsniveau)
82,50%
Oordeel controleur
Akkoord
160 (100%)
Aantal eisen te authoriseren per persoon
Carlo Hendriks
Voortgang controleur (persoonsniveau)
100,00%
Documentstatus
Concept in bewerking
Concept ter autorisatie
Concept ter verificatie
Definitief
Workflow Status
1. Inplannen document
2. Opstellen
3. Verificatie Discipline
4. Verificatie Project
Action Rate for documents in workflow
Project timeline
Workflow for document status
8,20
Doel: 10,60 (-22.64%)
De tijdlijn links laat pieken en dalen in workflow activiteit zien. Pieken duiden op actieve beoordelingsperiodes of andere periodes waar de workflow actief bezig is. Dalen tijdens op weinig activiteit. Documenten zitten in dezelfde workflow. In andere woorden. Documenten veranderen niet van workflow status.
Idealiter wordt de KPI waarde bepaald op basis van workflow activiteit van historische projecten. Op deze manier kunnen trends worden voorspeld. Op deze manier is het mogelijk om eventueel 'hoge' activiteit aan te zien komen, waardoor hier waar nodig vroeg op kan worden ingespeeld.
Verificatie vertraging
16
CountEarly
1
CountOnTime
23
CountLate
7,02
AVPT_Planned
26,90
AVPT_Actual
AVPT_Actual en AVPT_Planned per Date
12,00
Doel: 7,00 (-71.43%)
De gemiddelde verificatie tijd laat zien hoelang documenten over verificatie hebben gedaan ten opzichte van de periode van de voren vastgelegd in M-Files.
De KPI doel waarde is de waarde die van te voren in M-Files is vastgelegd. Dit is het aantal dagen dat staat voor het verificatieproces.

# 10 Discussion

*This chapter reflects on the findings, methodological validity, and broader research implications. Section 10.1 provides a discussion about the interpretation of the findings, section 10.2 discusses the validity of the research, section 10.3 discusses the limitations, and section 10.4 discusses the added value of the research.*

## 10.1. Interpretation of the findings

This section critically reflects and interprets the research findings about theoretical frameworks and practical applications. It begins with an evaluation of the DPMT's performance, followed by a reflection on the role of milestones, KPIs, and indicators within the tool. Subsequently, the discussion explores how the DPMT addresses key challenges identified in literature and practice, particularly in complex design processes and fragmented information flows. The section concludes by highlighting key discrepancies between theoretical expectations and real-world implementation.

### 10.1.1. Effectiveness of the DPMT

The DPMT developed in this research was intended to address the theoretical and practical challenges. The development of the DPMT represents a concrete response to the complex, data-related challenges faced by infrastructure design teams. Its value lies not in inventing new systems, but in bridging the gaps between existing tools and data streams that were previously disconnected. Further, the DPMT should be a solution to the problem statement defined earlier in this research:

> *While the design phase plays a critical role in laying the foundation for a project, delays frequently arise due to a lack of situational awareness, particularly in managing milestones and navigating fragmented data systems. Although data-driven tools are available, there is currently no structured framework that effectively enhances real-time insight and coordination to prevent delays during this phase.*

Its effectiveness was evaluated through a focus group, and the results indicate several clear benefits and some limitations. First, the DPMT significantly improved the visibility of information on design progress. Aggregating data from multiple sources into one dashboard created a single, consolidated overview that had not existed before. Participants noted that *"there is no place where it all comes together like this"* in the current way of working. The integrated view significantly enhanced situational awareness, instead of checking design progress throughout the different systems. Secondly, the tool proved to be user-friendly and aligned with existing workflows. Since it was implemented using Power BI, there was a low barrier to its implementation. The dashboard used intuitive visual graphs, which users found straightforward to interpret.

Before the development of the DPMT, twelve functional, structural, and environmental requirements were formulated based on challenges identified in the literature and findings from the interviews and case study. These requirements, summarized in table 10.1, served as design criteria to ensure the tool would address core issues. These requirements are revisited to assess whether the DPMT meets the intended goals. Although a formal, criteria-by-criteria evaluation was not conducted, the requirements are critically reflected using the insights gathered during the focus group session. This approach enables a qualitative assessment of how well the tool responds to practical needs and theoretical expectations, and helps identify areas for improvement in future iterations.

Many of the predefined requirements were confirmed as fulfilled. For instance, the requirements about clarity and usability of the DPMT (REQT 5, REQT 10, REQT 11) were repeatedly mentioned by participants as key strengths of the DPMT. The inclusion and visual presentation of KPIs (REQT 3) were also positively received, providing users with actionable insight into the design process. Furthermore, integrating data from multiple systems was seen as an improvement compared to the current fragmented overview (REQT 1). However, this integration is currently limited to M-Files and Relatics; data from ACC has not yet been incorporated.

Other requirements, however, were only partially met. In particular, requirements related to automation (REQT 4, REQT 6) and predictive capabilities (REQT 8, REQT 12) were not fully implemented. The foundation for REQT 4 and REQT 8 is present in the DPMT; however, implementing an Early Warning System (EWS) requires historical data from previously completed projects to enable automation. Nonetheless, the current DPMT supports earlier risk detection by visualizing trends and anomalies through the available indicators. REQT 6 and REQT 12 relate to the automatic extraction of data. While the DPMT establishes the foundation for this functionality, the implementation of real-time data extraction via APIs and a centralized database was beyond the scope of this research. These partially addressed requirements primarily reflect functional ambitions that extend beyond the current capabilities of the tool, as their implementation fell outside the scope of this research. As a result, the DPMT has evolved from a conceptual artefact to one tested against the realities of project management at Heijmans. The insights gained from this first iteration will feed into the next development phase, during which the tool will be refined and tested further.

**Table 10.1:** Requirements reflection and whether these are addressed by the DPMT

| # | Requirement | Addressed by DPMT |
|---|---|---|
| REQT 1 | The method must use data from M-Files, Relatics, and ACC, ensuring a unified approach to design tracking. | ✓ |
| REQT 2 | The method should define milestones for the VO, DO, and UO phases. | ✓ |
| REQT 3 | The method should support using Key Performance Indicators (KPIs) to track design progress instead of manual updates. | ✓ |
| REQT 4 | The method must incorporate early warning signals (EWS) that flag potential delays based on predefined performance indicators. | ⚠ (no predictive alerts yet, but risk indicators are present) |
| REQT 5 | A visual dashboard, potentially using tools like Power BI, should provide a clear and intuitive overview of the design phase. | ✓ |
| REQT 6 | The method must integrate with M-Files, Relatics, and ACC, avoiding the need for additional software/programs. | ⚠ (integration not yet automated) |
| REQT 7 | The tracking system should support coordination within and across different design disciplines. | ✓ |
| REQT 8 | The method should automate design tracking and reporting, minimizing manual effort. | ⚠ (automation not yet implemented) |
| REQT 9 | The method must be flexible enough to be applied to projects of varying sizes and complexity levels. | ✓ (tested on component-level; scalable structure) |
| REQT 10 | The method should be intuitive and easy to use, allowing design managers and design leaders to adopt it without needing training. | ✓ |
| REQT 11 | The method should ensure that information is presented clearly and structured so users can quickly assess progress at a glance. | ✓ |
| REQT 12 | The method should minimize manual effort. Further, it must integrate into the existing workflow at Heijmans, ensuring its adoption enhances rather than disrupts ongoing processes. | ⚠ (manual input still required; integration foreseen) |

All identified requirements share a common objective: enhancing situational awareness during the design phase. The Design Phase Monitoring Tool (DPMT) developed in this research is more than a functional dashboard; it marks a foundational shift in how design processes are managed within complex infrastructure projects. By integrating fragmented data from core systems such as Relatics, M-Files, and Autodesk Construction Cloud, the DPMT facilitates shared understanding among stakeholders. Grounded in Endsley's model of situational awareness, the tool enables teams to perceive current progress, comprehend its implications, and project potential risks. This capability supports a cognitive transition from reactive to proactive management—an essential need emphasized in literature and expert interviews. Rather than treating data as a static record of past events, the DPMT positions it as a dynamic guide for future action. It transforms siloed and disconnected information into structured insights, enabling project leaders to plan more confidently and respond more effectively to emerging issues. In doing so, the tool addresses one of the main barriers to design coordination: the lack of visibility across disconnected systems. With continued refinement, the DPMT has the potential to evolve into a standard framework for managing the increasingly complex and data-driven nature of infrastructure design phases.

### 10.1.2. Reflection on milestones, KPI groups, and indicators

The effectiveness of the DPMT depends on the selected milestones, KPI groups, and indicators. This section discusses the effectiveness of the selection input for the DPMT. Incorporating KPI groups and indicators to monitor progress represented a key shift from manual updates to a more analytical and real-time approach.

The selection of the indicators followed an iterative process combining theory and practice. Initially, indicators from theory and insights gained through interviews were combined. An importance index was developed to structure and prioritize this list. A Google Forms survey was conducted to select the most relevant and actionable indicators. Experts were asked to rate each indicator on a scale from 1 (no insight) to 5 (a lot of insight). However, the results remain somewhat exploratory due to the relatively small sample size and the professional backgrounds of the respondents, primarily in design coordination and project management. Indicators that may be more relevant to other disciplines, such as systems engineering or quality control, may have been under-represented.

In addition, the usefulness of specific indicators was partly constrained by data quality and consistency. For example, the effectiveness of verification-related metrics relied heavily on structured metadata and consistent workflow status updates in Relatics and M-Files. In cases where such practices were not followed, indicators became incomplete or potentially misleading. This highlights the importance of aligning digital workflows with indicator design—a similar limitation applied to lean planning and activity-based tracking indicators. Despite being rated highly valuable by participants, the current reliance on analogue methods, such as physical sticky notes, prevented these indicators from being included in a data-driven format within this research. As a result, their potential remains theoretical until digital integration practices are improved.

Additionally, while indicators such as verification delay or action rates show potential for predictive analytics, their current use is limited to retrospective insight. Without historical data across multiple projects, trend-based early warning mechanisms cannot yet be implemented. Nonetheless, these indicators already contribute to situational awareness, and their structured implementation lays the foundation for future enhancements in prediction and automation.

The creation of the KPI groups was a direct outcome of the selected indicators. Rather than being predefined, the groups were formed inductively to provide structure and clarity to the diverse set of indicators identified through literature and expert input. However, this approach also implies that the KPI group structure is inherently flexible and sensitive to changes in indicator selection. If different indicators had been prioritized, such as those related to cost tracking and interdisciplinary coordination, this could have led to entirely new KPI groups or a redefinition of existing ones.

### 10.1.3. Challenges of Data-Driven Design Management: Theory vs. Practice

The effectiveness discussed in the previous section can be further contextualized by discussing the broader theoretical and practical challenges of DDDM. Literature on DDDM highlights several challenges faced by project teams, including data integration issues (Arnarsson et al., 2018), lack of actionable insights (Bertoni, 2018), fragmented information (Wilberg et al., 2017; Lohman et al., 2003), and the continued need for human interpretation of data (Johnson et al., 2023; Lohman et al., 2003).

Theoretically, four key bottlenecks have been identified: data availability and quality, mismatch between requested and provided information, poor self-assessment of information needs, and ineffective use of information (Lohman et al., 2003). A challenge lies in the fragmentation of important project data across disparate systems (Bertoni, 2018). This separation undermines situational awareness and impedes real-time insight into the overall design progress. Consequently, problems are often identified too late, resulting in delays. Moreover, theory emphasizes that the presence of data alone is not sufficient; data must be reliable, up-to-date, and embedded with a meaningful context (Arnarsson et al., 2018; Lohman et al., 2003; Wu et al., 2013). Data is incomplete, inconsistent, or outdated in many organizations, leading to flawed decision-making (Bertoni, 2018). Thus, effective DDDM demands access to data and its transformations into trustworthy information. In addition, theoretical frameworks stress the indispensable role of human interaction. Data, even when well-organized, does not inherently convey knowledge. Design managers and leaders must interpret analytical outputs, contextualize patterns, and apply their expertise to make informed decisions (Johnson et al., 2023). This creates a paradox within DDDM: *while enhanced data and integration promise improved control, the ultimate value of such systems depends on the human ability to interpret and act upon them.*

The case study and interview results confirmed these theoretical challenges in practice. Information was distributed across multiple systems: Relatics for requirements, M-Files for documents, and ACC for models and drawings, complicating efforts to obtain a clear, timely picture of progress. Interviewees frequently expressed difficulty in answering fundamental questions such as *"are we on track with our design deliverables?"* or *"which deadlines are at risk?"*, essentially because relevant data was not readily accessible or presented. This validates the literature's argument that fragmented data leads to delayed problem identification and reduced process visibility.

Practice also highlighted the role of human effort in bridging data gaps. Before the introduction of the DPMT, managers relied on informal methods, personal tracking via Excel sheets, regular meetings, and professional intuition to approximate the project's status. Even after the DPMT was introduced, human interpretation remained essential. Concepts such as "workflow efficiency" or "action rate" were initially unclear to some users, illustrating that only presenting data is insufficient unless clear, comprehensible definitions and visualizations accompany it.

The challenges identified in practice were grouped into three overarching domains: data & system, organizational & process, and team. The DPMT was developed to address all three. From a technical perspective, the tool reduces data fragmentation by integrating multiple platforms into one dashboard. This enhances visibility and directly addresses one of the key bottlenecks identified in theory: the issues of data availability and quality (Lohman et al., 2003).

On an organizational level, the DPMT introduces a standardized structure and clearly defined KPI groups and performance indicators. This helps align expectations and workflows, reducing the risk of a mismatch between requested and provided information, addressing the second bottleneck. By structuring data, the DPMT makes it easier to track whether key deliverables are completed on time and in the expected format.

At the team level, the DPMT translates complex datasets into accessible and intuitive visualizations. This enables design managers and leaders to interpret progress without needing advanced skills. As such, it supports better self-assessment of information needs and encourages the effective use of information, addressing the third and fourth bottlenecks found in theory.

Another critical challenge that emerged during the demonstration and evaluation of the DPMT relates to change management. In theory, digital tools should support structured change control by providing transparent, traceable records of requirement updates, design modifications, and decision approvals. As described in the literature, to be effective, such a system must not function as a "black box" (Bertoni, 2018). However, the lack of formal change logs and the inconsistent use of metadata, such as reasons for change or timestamps, made it difficult for the DPMT to capture and track changes fully. This reflects a broader challenge in adopting digital tools: their effectiveness depends not only on technical capabilities but also on the consistency and reliability of data input and maintenance within the organization.

Although limitations remain, such as automation and real-time data extraction, the DPMT represents a theory-informed and practical response to DDDM challenges.

### 10.1.4. Information flow and use of multiple systems

Many challenges discussed earlier are closely linked to how information flows through systems, teams, and processes. As such, understanding and improving information flow is essential to addressing these issues in a structured and sustainable way. A recurring theme in both theory and practice is the presence of information flow bottlenecks. Theoretically, when project information is scattered across unconnected systems, it results in isolated "islands" of data (Love et al., 2018). This fragmentation hampers real-time insight and creates barriers to efficient coordination. As noted in the literature, adequate information flow is a cornerstone of lean project delivery and design management; poor flow leads to rework, misalignment, and delayed responses to emerging issues (Sacks et al., 2010). In particular, fragmented systems interrupt the continuous feedback loops for timely verification, decision-making, and milestone tracking.

These theoretical challenges were mirrored in the practical findings of this research. Using separate platforms meant that no single point of truth existed regarding the project's design status. Design managers had to manually cross-reference multiple systems to determine whether a milestone was genuinely achieved. This reliance on manual integration consumed time and increased the risk of errors, outdated information, and inconsistent reporting.

As a result, situational awareness at the project level was often compromised. Design leaders were forced to fill the gap left by poor system integration by depending on workarounds like spreadsheet trackers and frequent coordination meetings. These methods, while helpful, were reactive and inefficient. The introduction of the DPMT directly addressed this issue by aggregating critical design data into a unified dashboard. This integration significantly improved information flow, enabling team members to access up-to-date, contextualized information without switching between systems or interpreting disconnected data points.

Both literature and practice affirm that information flow is a key enabler of proactive design management. When data moves fluidly between stakeholders and systems, teams can maintain a shared understanding of project progress, identify risks earlier, and make better-informed decisions. In contrast, fragmented information flows foster a reactive management style, where issues only surface during coordination meetings, which is too late for timely intervention. By improving the flow of information, the DPMT enhances visibility and supports a more anticipatory approach to managing the design process.

### 10.1.5. Complexity of design process

Applying the Stacey framework to design management highlights the importance of adaptive workflows, continuous feedback, and traceability mechanisms when operating in complex environments. The framework cautions against rigid control methods for managing complexity, instead advocating for systems-thinking approaches that enable iterative learning and convergence toward shared goals (Stacey, 1996; Cicmil et al., 2006; Bosch-Rekveldt et al., 2011). The case study findings echoed this perspective: although a high-level Primavera schedule was available as a reference, designing tasks required constant coordination and real-time adjustments across disciplines. Each discipline maintained its detailed planning, continuously updating its contribution to the broader timeline, illustrating the inherently adaptive nature of design management.

This understanding of complexity informed the development of the DPMT. Rather than focusing solely on whether milestones had been achieved, the tool was designed to monitor underlying performance indicators—such as the number of finalized documents or the percentage of verified requirements—that provide insight into progress. In this way, the DPMT does not directly aim to link KPIs to milestones. Instead, it offers a set of indicators that reflect the status and health of ongoing design activities, allowing teams to promptly assess whether they are progressing *toward* milestones. This shift from static milestone tracking to continuous performance monitoring aligns with Stacey's argument that management in complex contexts should prioritize feedback and learning over rigid control.

By visualizing indicators, the DPMT encourages teams to ask proactive questions such as *"Are we progressing as expected?"* or *"which areas require attention?"* rather than only checking off completed milestones. This early feedback loop enables earlier detection of issues and supports better-informed decision-making. As the project advances into more predictable stages, where uncertainty diminishes, the same dashboard can support a more structured management style by clearly highlighting deviations from the expected trajectory. In this way, the DPMT bridges adaptive and traditional management approaches by providing tools for both early-stage complexity and later-stage control.

### 10.1.6. Discrepancies between theory and practice

By comparing the theoretical ideals of data-driven design management with the realities observed at Heijmans, it is possible to identify where they align and where there are gaps. Generally, the practical results affirm many theoretical expectations: it showed that integrating data from previously siloed systems into one platform does improve situational awareness and can potentially reduce delays (as theory predicted). However, certain discrepancies between theory and practice emerged.

One such discrepancy is in the ease of implementation. Theoretically, the concept of a unified, real-time dashboard for design management sounds straightforward, but its development encountered hurdles like data readiness and system integration challenges in practice. For instance, theory emphasizes advanced capabilities like predictive analytics and AI once data is integrated. Still, the research revealed that a lot of groundwork was and is needed before reaching that stage – some information had to be cleaned or even simulated to fill gaps in the proof-of-concept. This indicates that practical limitations (legacy systems, incomplete data capture) can slow the realization of theoretical benefits.

Another subtle difference lies in managing complexity. The literature (e.g., Stacey's framework) advocates a flexible, adaptive management approach in high uncertainty, suggesting that rigid milestone enforcement would be counterproductive. In reality, construction projects still operate under fixed contractual milestones and deadlines that cannot be easily shifted. The case study highlighted this tension: while the tool provided insight to manage complexity better, the team still had to adhere to specific hard deadlines. Therefore, a data-driven tool can help navigate complexity but does not remove external pressures.

Additionally, theory often assumes that more information leads to better decisions, but practice has shown that more information must also mean the correct information, presented in the right way. Suppose the dashboard floods users with data or uses terms they aren't familiar with. In that case, the potential benefits might not fully materialize (information overload or confusion can occur), reflecting what literature describes as a mismatch between provided information and user needs.

Crucially, the practical results underscore the importance of the human and organizational aspects in data-driven innovation. Theoretical frameworks might underplay user adoption, trust, and change management issues. In practice, these turned out to be significant. For instance, even though the DPMT delivered valuable insights, its ultimate success depends on the project team trusting the dashboard and incorporating it into their daily routines. If some team members continue to rely on their old spreadsheets or gut feeling, the tool's impact would be limited—the focus group remarks about needing automated updates to trust the dashboard.

## 10.2. Validity and reliability of the research

The validity of this research is discussed in terms of the literature review (Chapter 10.2.1) and the research design (Chapter 10.2.2).

### 10.2.1. Literature review

The literature review was designed to ensure enough context to identify relevant concepts, challenges, and developments related to the research. The literature was verified or extended by recurring themes identified in interviews to enhance validity, ensuring alignment between theoretical insights and practical challenges. While the focus of this research necessarily bounded the scope of the review, the included literature provided a robust foundation for developing the DPMT. It helped identify gaps that the tool aimed to address. As such, the literature review contributed to the conceptual grounding of the tool and the credibility of the identified indicators and solution objectives.

The literature review had both strengths and limitations. One of the main challenges was the limited depth in some areas. Because the review covered a broad range of topics, not every aspect could be explored in detail, which means that specific components that might have strengthened the research design could have been overlooked. At the same time, this broad scope was also one of the review's biggest strengths. It helped build a solid understanding of several important themes, from milestone management to information flow and data integration, which was necessary to shape the research direction and ensure the design of the DPMT addressed the sub-questions and overall research aim.

### 10.2.2. Research design

The research adopted the Design Science Research Methodology to address the practical problem. The aim was to develop an artefact - the DPMT - that integrates data from existing systems and provides insight to support design managers and leaders in tracking progress, identifying risks, and making informed decisions. The research design was structured around the six stages of DSRM:

- **Problem identification and motivation:** Based on interviews and literature, the lack of real-time, integrated monitoring tools for the design phase was identified as a key challenge.
- **Definition of objectives for a solution:** The solution aimed to enhance situational awareness by visualizing the status of key design processes (e.g., document finalization and requirement verification) using existing systems such as Relatics and M-Files.

- **Design and development:** The DPMT was developed as an interactive Power BI dashboard, featuring KPIs such as verification progress, document completion rates, and rework frequency. The tool was structured around lean design flow principles to support weekly monitoring and decision-making.
- **Demonstration:** The tool was applied to data from a completed Heijmans Infra project as a *proof of concept*. This allowed for an initial evaluation of its feasibility, usability, and potential to generate actionable insights from existing datasets.
- **Evaluation:** A focus group involving Heijmans design managers and leaders confirmed the tool's practical relevance and usability. Suggestions for future improvements included the addition of predictive milestone forecasting and real-time system integration.
- **Communication:** The results and the developed artefact are documented in this thesis to contribute to academic research and practical applications in data-driven design management.

The research results are examined by considering four commonly used quality criteria: *construct validity, internal validity, external validity, and reliability* as suggested by Yin (2018).

**Construct validity**
Construct validity determines whether the DPMT complies with the problem definition. This research was intended to solve the problem as defined in Chapter 1.

Several strategies were applied to enhance construct validity. First, the selection of indicators for monitoring the design process was informed by both literature and insights from interviews with practitioners. The variables included in the DPMT were chosen based on recurring themes identified through qualitative analysis in Atlas, ensuring that they reflected the most pressing challenges experienced in practice.

Second, expert feedback played a central role in validating the relevance and clarity of the indicators. KPIs were only included in the dashboard if they were frequently mentioned across interviews or considered critical by subject-matter experts. This helped ensure that the tool focused on meaningful, actionable information.

While it was not feasible to incorporate every possible indicator, the selected metrics strongly align with the research objectives and the practical needs identified by stakeholders. As such, the DPMT's consistent focus on measuring what matters in relation to the core problem statement supports its construct validity.

**Internal validity**
Internal validity refers to the extent to which causal relationships and inferences made in the research are credible. Since this research is exploratory and focused on tool development, internal validity is mainly concerned with interpreting qualitative data and the tool's structure.

A potential threat to internal validity lies in the varied interpretations of key indicators, such as "workflow efficiency" and "action rate," by different interviewees. These terms lack standard definitions in industry practice, leading to inconsistent interpretations. Additionally, indicators were only included in the final DPMT if there was a clear, shared understanding of their meaning and applicability.

Another limitation affecting internal validity is the dashboard's practical validation. While a focus group confirmed the DPMT's conceptual soundness and perceived usefulness, it was not tested in an active, ongoing project. As a result, its effectiveness under real-time project conditions and its ability to support decision-making in dynamic environments remain partially unverified.

**External validity**
The external validation of this research is primarily limited to construction companies within the Netherlands. This is largely because many Dutch contractors follow comparable design processes, use the same or similar systems, and operate within a shared regulatory and contractual environment. As a result, the findings and the DPMT are likely to be most applicable to companies with similar digital maturity and project structures.

That said, while the DPMT was developed within the context of large and complex CAT3 infrastructure projects, its core principles are not limited to large-scale projects. Each project, whether small or big, has to deal with the same data; only the amount and complexity of the data can differ. With appropriate scaling and simplification, the DPMT could be adapted for smaller or less complex projects, as tracking the same kind of indicators is still possible. This opens up potential for broader applicability, as the DPMT becomes more widespread across different project sizes.

The validation session confirmed that the principles underlying the DPMT were recognizable and valuable to company experts. While the DPMT's applicability to other organizations has not yet been formally tested, it is reasonable to assume that the tool could be transferred, with some modifications, to other Dutch construction companies. This assumption is based on the observation that many contractors in the Netherlands operate under similar project delivery models, use comparable digital tools, and follow aligned processes for design development.

**Reliability**
Reliability refers to the consistency and repeatability of the research process. Efforts were made to ensure transparency and reproducibility throughout the research. All steps in the methodology, including interview design, data coding, and dashboard development, have been documented in detail. Therefore, reproducing the research is believed to reflect the same general outcome.

## 10.3. Limitations of the research

While the research achieved its objectives and provided valuable insights, it is important to acknowledge several limitations that affect the interpretation and generalizability of the findings. The limitations have been addressed throughout the discussion. However, for readability, the main limitations are summarized below:

- **Context-specific development:** The DPMT was developed based on the data structures, workflows, and tools used within Heijmans. As such, its generalizability to other companies or project contexts may be limited, particularly where different systems or project management approaches are used.
- **Scope of data systems:** The research focused specifically on Relatics and M-Files. Other potentially relevant systems were not included, which may limit the tool's applicability.
- **Data completeness and accessibility:** The DPMT's effectiveness is limited by the completeness and accessibility of data within its source systems. Although most of the required data was available, some datasets could not be exported during this research, leading to the use of simulated values.
- **Dependency on design managers and leaders and system knowledge:** The successful use of the DPMT depends on the expertise of design managers and leaders, particularly their familiarity with design processes, data systems, and PowerBI. This reliance may affect the DPMT's effectiveness in teams with lower digital maturity.
- **Indicator scope:** Although several potential indicators were defined, the DPMT included only a selection of those. Not all suggested or theoretically relevant metrics were implemented.
- **Unimplemented exploratory features:** Suggestions for advanced features were discussed during interviews and focus groups. However, their feasibility was not assessed within this research. These features remain conceptual and unvalidated.
- **Feedback subjectivity:** The evaluation of the DPMT was based on an internal focus group. Broader validation across different roles or companies may yield additional or differing insights.

## 10.4. Added value of the research

Despite some limitations, this research offers significant contributions to academic knowledge and practical project management.

### 10.4.1. Scientific relevance

From an academic viewpoint, this research advances the field of construction management by filling a noted gap. It provides a structured methodology and artefact (the DPMT) for design-phase data-driven management, an area that had not been extensively explored. Prior literature often stated the need for better information flow in design abstractly. The present research concretely instantiates this and measures its effects. Application of DSRM in such a context is also a methodology contribution as it illustrates how iterative development and evaluation may be used to address a real problem in construction management.

The method outlined can inform future studies as a template for linking raw data to performance outcomes in early project phases. Moreover, the research gave insight into which data is most valuable at different design decision points and how making that data actionable can influence team behaviour. This knowledge adds some nuance to academic discussions on project control: it shifts some focus upstream to design, showing that decisions made (or missed) in the design can set the trajectory for project execution. In summary, the thesis's scientific relevance lies in expanding the theoretical understanding of data-driven management into the design realm and demonstrating how combining information systems and management principles can lead to better outcomes in construction projects.

### 10.4.2. Practical relevance

Practically, the research is highly valuable for construction companies. It addresses a *core* problem: the lack of real-time visibility during design. By developing and validating the DPMT, the research provides a blueprint for practitioners to improve their processes. Construction firms can adapt the dashboard and underlying methods to create integrated monitoring systems. The immediate practical value is that it offers a clear picture of how to tie existing tools (requirements management, document control, scheduling) into one cohesive oversight mechanism. Companies often have these systems but use only a fraction of their potential.

The fact that industry experts responded very positively to the prototype indicates that the solution is aligned with on-the-ground needs and is user-friendly enough to be adopted, with comments highlighting how it could replace manual spreadsheets and save time. The practical relevance is also seen in risk reduction: implementing such a tool could help project teams catch issues early, thus avoiding costly design rework or deadline extensions. In a broader sense, the research's outcomes encourage construction organizations to embrace data-driven practices. It provides evidence that investing in data consolidation and visualization yields tangible benefits like improved team communication, accountability (since data is transparent), and efficiency in design reviews.

Beyond the immediate benefits of the DPMT, the research set the stage for future innovation. The structure and data foundation of the DPMT can act as a *stepping stone* towards more advanced applications, such as AI-driven early warning systems, predictive analytics using machine learning, or even integration with digital twins. By consolidating and visualizing data streams, the DPMT creates the type of structured dataset on which these technologies depend. This opens the door to next-generation solutions.

Conclude, the practical contribution of this thesis is a validated, adaptable proof-of-concept that doesn't require heavy investment or custom development to get started. With tools like Power BI, which are already widely used, construction firms can begin improving performance almost immediately. And by doing so, they lay the groundwork for more intelligent, resilient, and data-savvy design management in the future.

# 11
# Conclusion & Recommendations

*This chapter marks the conclusion of this research by providing concise answers to the research questions. Section 11.1 provides answers to the sub-questions based on the preceding chapters. Based on those answers, the main research question will be answered. The chapter ends with recommendations for future research and practice.*

## 11.1. Answer to the research questions

To achieve the research goal, a central research question and sub-questions were formulated. The remainder of this section will provide answers to the sub-questions, followed by the answer to the main research question.

> *SQ1: "What are the current trends and challenges of data-driven design management in the design phase of projects, and how are milestones currently managed?"*

The construction sector has a clear trend towards using data to enhance design processes and related decision-making. The idea of *data-driven design* is increasingly seen as a paradigm shift, offering many new opportunities. Many organizations are now exploring how all this data can help them. This growing interest is also reflected in academic research: since around 2016, there's been a notable increase in publications on this topic (Bertoni, 2020).

Data is used to detect patterns, highlight trends, and help create an overview, making the design process more efficient and transparent. This idea often involves creating a "knowledge platform" that links project data with storage and feedback mechanisms, enabling better reuse of insights from previous projects and enhancing current and future design phases (Hofstee, 2018).

That said, applying a data-driven approach comes with several practical challenges. Those challenges can be categorized into data & system-related, organizational & process-related, and team-related. One of them is that project data is scattered across different systems Wilberg et al., 2017. This fragmentation makes it difficult for design managers and leaders to maintain a clear and complete overview of the overall progress; this lack of integration limits situational awareness. On top of that, data quality can be a problem: missing, outdated, or inconsistent entries can make insight unreliable unless cleaned and maintained properly (Lohman et al., 2003; Wu et al., 2013; Arnarsson et al., 2018). Structuring and validating data requires effort before it can truly support day-to-day decisions. There's also the human side to consider (Johnson et al., 2023; Lohman et al., 2003). Even with a well-designed dashboard, experienced professionals are still needed to interpret what the data means in the broader project context.

Finally, introducing new tools and dashboards can meet resistance within organizations. Not everyone is quick to adopt unfamiliar systems or workflows, especially when they are used to handling things their way. The research also found that inconsistent data entry and usage further limit the value of integrated systems. And in complex projects, the sheer volume of data can become overwhelming if not visualized clearly, potentially causing teams to lose sight of the bigger picture.

But how can data support milestone tracking? Milestones in the design phase are currently managed using traditional planning methods. A master schedule made in Primavera is used as the primary steering tool. This schedule outlines key phase milestones, such as the delivery of the three design phases. Each discipline then develops its detailed planning. To support coordination, those disciplines summarize their plans in weekly Excel overviews. Concepts such as Lean Planning are used to support milestone tracking but are primarily based on conventional, old-fashioned ways of using sticky notes. Alongside those methods, most teams maintain a separate document planning overview to track which documents must be delivered. Despite these practices, milestone and design phase monitoring are primarily based on recurring meetings and the ”gut feeling” of design managers and leaders.

Weekly design meetings and cross-disciplinary sessions are used to assess progress toward milestones. However, there is no centralized, real-time overview. Managers often rely on verbal updates and personal judgments, which can lead to surprises. Moreover, milestone structures typically only include the major phase completions (VO, DO, UO) and formal gate reviews. Intermediate checkpoints are often missing, which limits visibility into progress between major deadlines. Several interviewees expressed concern over this lack of granularity, with one describing such broad planning without interim milestones as “unmanageable.”

In summary, while data-driven approaches offer promising tools for enhancing design phase transparency and efficiency, their implementation is still hindered by challenges related to data & system and organizational barriers. Meanwhile, milestone tracking and situational awareness of the design phase remain largely manual and informal, underscoring the need for more integrated and data-informed monitoring methods. To enhance these approaches, the findings from sub-question two offer essential insights into potential improvements.

> *SQ2: ”What can be monitored within the current data systems, and what are the indicators that create insight into the design progress?”*

A substantial amount of potentially valuable information is available within the current data systems used during the design phase. The findings of this research indicate that various aspects of the design process can be monitored using existing data systems, such as Relatics, M-Files, and planning tools. Although no standardized approach exists within practice, this research has shown that valuable insight into design progress can be obtained by extracting and structuring available data. Therefore, it is concluded that the sub-question is supported: meaningful monitoring is indeed possible within the current data landscape, provided that relevant indicators are defined and linked to system outputs.

The research showed that project teams rely on manual progress tracking and fragmented system use, resulting in limited situational awareness. In response, this research proposes a structured approach by developing four KPI groups:

- Management of document readiness
- Management of requirements and changes
- Management of risks
- Management of time tracking

Within each group, specific indicators were formulated using a combination of literature and empirical input from expert interviews. These indicators were refined during iterative tool development, and only those consistently recognized by practitioners as insightful were retained. As such, the selected indicators go beyond descriptive outputs: they act as signals for progress, coordination issues, and potential delays.

**Table 11.1:** Indicators per KPI group

| KPI 1 | KPI 2 | KPI 3 | KPI 4 |
|---|---|---|---|
| Number of documents with a certain document status | Number of verified requirements | Number of risks with mitigation measures | Verification flow efficiency |
| Number of documents in the workflow | Number of open requirements | Number of outstanding risks | Verification delay |
| Document planning | | | Average verification processing time |
| Number of validation rounds | | | |

The nature of these indicators is process-oriented, as proposed by Haponava and Al-Jibouri (2010). For example, the document readiness group includes metrics such as the number of documents approved, in progress, or pending review. The requirements and changes group comprises the percentage of verified requirements and the number of late-stage changes. These indicators help design teams shift from reactive milestone tracking to proactive progress management. A complete overview of all indicators is provided in Section 6.2.2.

In summary, current systems offer substantial monitoring potential when paired with a structured, indicator-based approach. The indicators developed in this research form the foundation for improved situational awareness in the design phase and enable objective, real-time progress tracking. These insights directly inform the development of the monitoring approach, further addressed in the following sub-question.

> *SQ3: "How can data be structured and managed in the design phase to address each indicator and increase situational awareness directly?"*

To effectively use data as a basis for decision-making in the design phase, it must be structured and managed coherently and purposefully. The findings of this research show that this can be achieved by implementing a suitable system architecture, built around a set of predefined indicators as identified in sub-question two. This requires several key components:

- **Integrated data architecture:** Instead of fragmented data storage across individual systems, a central database is proposed to consolidate all relevant design-related data. The proposed DPMT concept includes an architecture in which data is automatically extracted from source systems and transferred to a central environment. Although this research's prototype does not yet include automated data integration, due to the research scope, it demonstrates the potential value such an architecture could bring once implemented.
- **Unified identifiers and data mapping:** To merge data from different systems, defining shared keys and structural mappings is essential. The DPMT links information based on unique identifiers such as document IDs or names. This enables a coherent view of documents, requirements, and planning data across systems.
- **Automated calculation of indicators:** Once the data is collected and properly linked, Power BI (or a similar tool) can automatically calculate the defined indicators. These indicators form the foundation of the monitoring approach and provide direct insight into progress, delays, and coordination issues.
- **PowerBI:** Power BI can structure and manage design data by linking information from systems like M-Files, Relatics, and ACC. It enables the creation of clear indicators and presents them in a visual dashboard. This setup gives teams a real-time overview of milestone performance and helps identify delays early.

In short, design phase data can be used most effectively by centralizing relevant information, logically connecting it, automating indicator calculations, and visualizing the results in an accessible way. This structured approach enables a continuous and transparent view of design progress. As a result, deviations or trends become immediately visible, allowing teams to respond directly to emerging issues.

Where a design manager might previously have discovered a delay only after several weeks, they can now be alerted within days through a real-time dashboard. This creates a feedback loop that supports continuous learning and adjustment throughout the design phase. Now that it is clear how data should be structured and used, it is possible to answer the final sub-question.

> *SQ4: "How can construction companies leverage the tool to enhance control over milestones and reduce the risk of delay?"*

The key mechanism by which the tool supports creating situational awareness lies in its ability to transform fragmented data originating from document management systems (e.g., M-Files) and requirement platforms (e.g., Relatics) into structured indicators linked to specific milestones. By organizing this data into four core KPI groups, the DPMT offers actionable insight into short-term performance and long-term milestone reliability.

The tool enables early detection of risks that could threaten milestone delivery. By continuously monitoring indicator trends, design managers and leaders can identify deviations from the expected trajectory at an earlier stage. In doing so, they shift from reactive problem-solving to proactive project control. Instead of learning too late that a milestone cannot be met, the tool flags potential issues while there is still time to intervene.

Moreover, the tool enhances transparency within and across teams. Because it is built on objective data from systems already in use, the dashboard can be shared across disciplines and project levels without relying on manual updates or subjective assessments. This fosters a shared understanding of progress and helps align expectations, reducing miscommunication and ambiguity.

The dashboard's visual and interactive nature also improves usability. Project managers and design leads can filter by component, discipline, or phase, making it easier to focus on the areas that require attention. The tool's traffic light logic (e.g., red, yellow, and green indicators) further supports fast interpretation and facilitates decision-making during meetings.

All answers above can be added together to answer the main research question of this research:

> *" How can construction companies enhance situational awareness during the design phase by integrating data from multiple systems, to support better milestone monitoring and reduce the risk of delays?"*

The findings of this research indicate that construction companies can enhance situational awareness during the design phase by integrating data from multiple systems into a structured monitoring environment. Rather than introducing new tools or replacing existing workflows, the proposed approach focuses on reorganizing and connecting data already available in systems such as M-Files, Relatics, and planning platforms. When systematically linked and visualized through carefully defined indicators, this data provides continuous insight into design progress, enabling project teams to detect risks early and steer more effectively toward key milestones.

To support this, a monitoring tool (DPMT) was developed and tested in this research. The tool is structured around four key KPI groups, each containing indicators grounded in literature and practical input. These indicators—such as the number of approved documents, percentage of verified requirements, or volume of actions in review workflows—provide meaningful signals that reflect the underlying status of the design process. The indicators help translate planning intent into measurable, traceable performance by connecting to specific phases or milestones.

Central to this approach is the integration of data from multiple systems. In current practice, data remains fragmented across platforms, leading to limited visibility and slow reaction to problems. The tool consolidates information into a unified dashboard by linking datasets based on shared identifiers, such as document IDs or component codes. This improves the accessibility and interpretability of progress data and allows for early detection of problems such as slow document flow, repeated rejections, or incomplete requirement verification.

The tool thereby enables a shift from reactive control to proactive management. Project teams can respond earlier and more effectively by making deviations visible as they emerge, rather than after deadlines are missed. The dashboard's visual cues—such as traffic light indicators and component-level filters—support faster interpretation and enable targeted follow-up actions across teams and disciplines.

Importantly, the findings suggest that relying solely on fixed milestone deadlines is insufficient in iterative design. Design processes are inherently dynamic and subject to continuous revision, feedback, and coordination. Rigid deadlines do not reflect the non-linear nature of this process and often fail to capture where issues arise. Instead, situational awareness—achieved through ongoing monitoring of process-based indicators—offers a more responsive and realistic alternative. It supports early intervention, promotes learning, and aligns better with the evolving character of design work.

In conclusion, construction companies can enhance milestone reliability and reduce the risk of delay by leveraging integrated, data-driven monitoring to increase transparency and responsiveness. By transforming scattered information into structured insight, they strengthen situational awareness and improve control over the design phase's complex, adaptive nature.

## 11.2. Recommendations

Given the insights derived from theoretical exploration and practical application, several recommendations can be made to bridge existing gaps and enhance data-driven design management in the construction sector. These recommendations are categorized into practical implementation actions and future scientific research directions.

### Practical Recommendations

- **Automate and integrate data sources:** The DPMT should be connected directly to Relatics, M-Files, and Autodesk Construction Cloud (ACC) systems to enhance usability and ensure real-time decision-making. Eliminating manual data exports will reduce effort, improve data reliability, and enable continuous monitoring. Static milestone deadlines currently limit the adaptability of the tool. Integration with planning software (e.g., Primavera, MS Project) would allow milestone timelines to update dynamically. This would ensure that performance indicators remain accurate and reflect the current project schedule. Future development should explore API-based integrations to enable secure and sustainable data pipelines, which Heijmans is already working on.
- **Expand system scope:** While this research focused on Relatics, M-Files, and ACC, additional data sources may offer valuable insights. For example, hours logged in ERP systems like SAP could provide indirect metrics on the time spent per design task. Exploring such links could offer a more comprehensive view of design productivity.
- **Incorporate lean planning and activity-based tracking:** Integration with tools that support Lean Planning (e.g., Takt planning or Last Planner System) and activity-based tracking methods would enable a more granular understanding of design flow, handovers, and delays. Such integration can further align design performance monitoring with production control principles.
- **Replace manual Excel-Based planning:** Many teams currently use simple Excel-based schedules during the design phase. However, these informal tools lack structured data that can be used analytically. Transitioning toward structured planning tools would make design schedules machine-readable and compatible with tools like the DPMT.
- **Develop reusable templates:** Creating a standardized, reusable DPMT template that can be applied across different projects would support knowledge transfer and accelerate adoption within Heijmans. Templates should allow for easy adaptation to project-specific contexts while maintaining consistency in KPIs.

### Scientific Recommendations

- **Explore predictive capabilities using Machine Learning:** Future research should investigate how historical project data can be used to train predictive models that forecast milestone risks, approval delays, or verification bottlenecks. This could evolve the DPMT from a monitoring tool to a proactive decision support system.
- **Broaden the context beyond infrastructure:** Though this research focused on infrastructure projects, the applicability of data-driven milestone monitoring to other construction domains (e.g., commercial buildings, industrial projects) warrants investigation. Comparative studies could help generalize the framework and identify sector-specific needs.
- **Ethical and Human use of monitoring tools:** As the use of dashboards and performance indicators becomes more common in the design phase, it's important to consider how these tools are experienced by the people who use them. While the intention is to improve collaboration and provide better insight into project progress, there is a real risk that monitoring tools may be perceived as controlling or overly focused on individual performance.

  Further research is needed to explore how these tools affect trust, team dynamics, and the overall working atmosphere. Understanding these effects can help ensure that monitoring systems are designed and introduced in a way that supports learning, openness, and a shared sense of ownership—rather than fear of being watched. A more human-centered and transparent approach to data use can contribute to a healthier data culture in the construction industry.

*“Data supports expertise – it doesn’t replace it.”*

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# A

# Interview outline (Dutch and English)

# Afstudeeronderzoek TU-Delft | J. (Jeroen van Schaik)

***"Enhancing data-driven control of milestones in the design phase of a infrastructure project"***

U wordt uitgenodigd om deel te nemen aan een onderzoeksstudie met de titel: "Verbeteren van datagestuurde controle van mijlpalen in de ontwerpfase van een infrastructuurproject." Dit onderzoek wordt uitgevoerd door Jeroen van Schaik als onderdeel van mijn masteropleiding Construction Management and Engineering aan de TU Delft en dient als input voor mijn masterscriptie.

Het doel van dit onderzoek is het ontwikkelen van een datagestuurd raamwerk om projectmanagement tijdens de ontwerpfase van bouwprojecten te optimaliseren. Door huidige praktijken te analyseren en belangrijke oorzaken van vertragingen te identificeren, streeft het onderzoek ernaar de mogelijkheid om ontwerp-mijlpalen effectief te volgen en te beheersen, te verbeteren. Dit onderzoek zal bijdragen aan een beter begrip van hoe data kan worden gebruikt om besluitvormingsprocessen te verbeteren, inefficiënties te verminderen en tijdige voltooiing van de ontwerpfase te waarborgen.

De interviews worden uitgevoerd om waardevolle inzichten te verkrijgen van ontwerpmanagers en leiders binnen de organisatie over de huidige uitdagingen en praktijken bij het beheren van ontwerp-mijlpalen. Het doel van deze interviews is om de specifieke factoren te identificeren die bijdragen aan vertragingen in de ontwerpfase en om inzicht te krijgen in de besluitvormingsprocessen die worden gebruikt om verschillende scenario's te beoordelen. Deze inzichten zullen de ontwikkeling van het voorgestelde raamwerk informeren en ervoor zorgen dat het aansluit bij de praktische behoeften en ervaringen van experts in de sector.

Om u voor te bereiden op het interview, bevat dit document de belangrijkste onderzoeksvragen. Het interview heeft een semi-gestructureerde aanpak, wat betekent dat deze hoofdvragen dienen als leidraad voor het gesprek, maar dat het niet beperkt is tot het beantwoorden van alleen deze vragen.

**Interview question**

1. Kunt u een korte introductie over uzelf geven?
2. Hoe bekend bent u met het concept van datagestuurd ontwerpmanagement?
3. Hoe beheert en volgt u momenteel mijlpalen in de ontwerpfase?
4. Met welke uitdagingen wordt u geconfronteerd bij het volgen en beheren van ontwerp-mijlpalen?
5. Hoe effectief ondersteunen uw huidige systemen (M-files, ACC, Relatics) het beheer van mijlpalen?
6. Hoe identificeert u momenteel vertragingen of risico's met betrekking tot mijlpalen tijdens de ontwerpfase?
7. Welke data zou u graag willen zien om mijlpalen effectiever te kunnen volgen?
8. Wat zijn volgens u cruciale factoren die bijdragen aan succesvol beheer van mijlpalen in de ontwerpfase?
9. Kunt u het typische proces beschrijven dat een ontwerpdossier doorloopt binnen uw datasystemen (bijv. M-files, ACC, Relatics), van creatie tot goedkeuring?
10. Is er nog iets dat u wilt toevoegen?

## Graduation Research TU Delft | J. (Jeroen van Schaik)

### "Enhancing Data-Driven Control of Milestones in the Design Phase of an Infrastructure Project"

You are invited to participate in a research study titled: **"Enhancing Data-Driven Control of Milestones in the Design Phase of an Infrastructure Project."** This study is conducted by Jeroen van Schaik as part of my Master's program in Construction Management and Engineering at TU Delft and serves as input for my master's thesis.

The goal of this research is to develop a data-driven framework to optimize project management during the design phase of construction projects. By analyzing current practices and identifying key causes of delays, the research aims to improve the ability to effectively monitor and control design milestones. This study seeks to contribute to a better understanding of how data can be used to improve decision-making processes, reduce inefficiencies, and ensure timely completion of the design phase.

The interviews are conducted to gain valuable insights from design managers and leaders within the organization regarding current challenges and practices in managing design milestones. The aim of these interviews is to identify specific factors contributing to delays in the design phase and to gain insights into the decision-making processes used to assess various scenarios. These insights will inform the development of the proposed framework and ensure that it aligns with the practical needs and experiences of industry experts.

To prepare for the interview, this document includes the main research questions. The interview follows a semi-structured approach, meaning that these primary questions serve as a guide for the discussion but are not limited to just these questions.

**Interview Questions:**

1. Could you please provide a brief introduction about yourself?
2. How familiar are you with the concept of data-driven design management?
3. How do you currently manage and track milestones in the design phase?
4. What challenges do you face when tracking and managing design milestones?
5. How effectively do your current systems (M-files, ACC, Relatics) support milestone management?
6. How do you currently identify delays or risks related to milestones during the design phase?
7. What data would you like to have to monitor milestones more effectively?
8. In your opinion, what are the critical factors that contribute to the successful management of milestones in the design phase?
9. Can you describe the typical process that a design file goes through within your data systems (e.g., M-files, ACC, Relatics), from creation to approval?
10. Is there anything else you would like to add?

# B

# Interview protocol (English)

# Interview outline: *Data-driven control of milestones in the design phase of a construction project.*

| | | | |
|---|---|---|---|
| **Introductie** | **Subject** | Data-driven control of milestones in the design phase of a construction project | |
| | **Goal** | Gather perspectives on current challenges and limitations / mapping the process. | |
| | **Confidentiality** | The mentioned project and participants will remain anonymous. | |
| | **Processing of results** | The interview will be transcribed and analyzed. The results will be included in the research report. | |
| | **Duration** | Duration: 45 to 60 minutes | |
| | **Interview conditions** | The interviewee agrees that the provided answers will be used for research purposes. Additionally, the interviewee agrees that the interview will be recorded to enhance the reliability of the research. | |
| | **Questions for the participant** | **Name:** | |
| | | **Employer:** | |
| | | **Responsibilities within the design process:** | |
| | | **Position:** | |
| | | **Years of experience:** | |
| | | | |
| **Interview part** | **Subject** | **Begin question** | **Follow-up question** |
| **Definition of data-driven design** | | 1) Are you familiar with the concept of data-driven design management?<br>*Yes -> Let them explain it and give context*<br>*No -> Explain the definition as made in the literature review* | |
| | | | |
| | | | |
| **Current practice milestones** | | 2) How do you currently manage and track milestones in the design phase? | 2.1) What tools or methods do you use to monitor the progress of these milestones? |
| | | | 2.2) Are there specific milestones you consider critical in the design phase? If so, which ones? |
| | | | 2.3) How consistent are these milestones across different projects? |
| | | | |
| **Challenges with milestones** | | 3) What challenges do you face when tracking and managing design milestones? | 3.1) Are there common issues that cause delays in achieving design milestones? |
| | | | 3.2) Do you think the current tools or systems you use are sufficient to address these challenges? Why or why not? |
| | | | 3.3) Can you provide me with an example of a recent project where a design milestone was delayed and what was the reason behind it? |
| | | | |
| **Data-systems** | | 4) How effective are your current systems (M-files, ACC, Relatics) in supporting milestone management? | 4.1) How accessible is the data you need to track milestones in these systems? |
| | | | 4.2) Are there any gaps in the data or system functionally that hinder milestone tracking? |
| | | | 4.3) What improvements would you suggest for these systems to make milestone management easier? |
| | | | |
| **Indicators** | | 5) How do you currently identify delays or risks related to milestones during the design phase? | 5.1) Do you use Key Performance Indicators (KPIs) of Early Warning Signal (EWS)? If yes, how effective are they? |
| | | | 5.2 What indicators or data would help improve you ability to foresee milestone delay? |

| | | | |
|---|---|---|---|
| | | | |
| | | 6) Which data would you like to see to monitor milestone more effectively? | 6.1) How would you like data to be structured or presented to help you? |
| | | | 6.2) What kind of visualizations or reports would be most useful for monitoring milestones? |
| | | | 6.3) Which data would you like to see to track milestones more effectively? |
| | | | |
| | | 7) In your opinion, what are crucial factors that contribute to successful milestone management in the design phase? | 7.1) What are 3 crucial factors for you? |
| | | | 7.2) How do these factors influence project outcomes? |
| | | | 7.3) Do you think addressing these factors can have influence on the delays in the design phase and why? |
| | | | |
| ***Question can only be asked to those that are involved in this process.*** | | 8) Can you describe the typical process a design document follows within your data systems (e.g., M-Files, ACC, Relatics) from creation to approval? | 8.1) How do you manage the review and verification stages for a document, and what are the common challenges faced during this process? |
| | | | 8.2) In your experience, are there any frequent issues related to version control or document revisions that impact milestone completion? |
| | | | |
| | | 9) Is there something else that you will add? | |
| | | | |

# C
# Workflow within ACC

In ACC, an issue can be defined as either a finding or an interface. Within these categories, there are three available types: general, design, and realization. Typically, users will create an issue in the category of findings. Therefore, for this research, two possible options remain:

- Category: Finding | Type: Design
- Category: Interface | Type: Design

After creating the issue, the user fills in various parameters.

| **Parameter** | **Value** | **Description** |
|---|---|---|
| Title | Title | Title of the notification |
| Status | Status | Status of the notification (See 'Notification Status') |
| Type | Type | Type of the notification (See 'Types and Root Causes') |
| Description | Description | Free text description of the notification |
| Assigned to | Assigned to | Person or role responsible for handling the notification |
| Watchers | Watchers | Optional, indicate whether persons should follow the notification |
| Location | Location | If defined, textual reference to the location |
| Location details | Location details | Free text description of the location |
| Due date | Due date | Date by which the notification must be addressed |
| Placement | Placement | Model where a pinpoint of the notification is placed |
| Root cause | Root cause | Optional, similar to type, additional information |
| References | Reference | Optional, additional information for the notification |
| Hotspot | Hotspot | Name of the hotspot if the issue is related to one |
| Comments | Comments | Free text field for adding comments |

The next step is setting the issue status.

| **Status** | **Explanation** |
|---|---|
| Draft | Status when not all required fields are filled in. |
| Open | Issue created and ready for response. |
| Completed | Issue answered and ready for approval. |
| Not approved | Response rejected; a new response is required. |
| Closed | Response approved, and the issue is closed. |

The ACC/Heijmans server is mainly used to store and manage models. While it also includes other design data, like calculations, drawings, and issues, its primary focus is on models. This makes it an important tool for keeping all design elements organized and ensuring everyone has access to the latest versions.

# D
# Four phases of development Heijmans

Figure D.1 illustrates the design process as it applies to the four design stages. Between each stage, the five steps of the design process, previously explained, are applied.


**Figure D.1:** The four phases of the design process

# E

# Artefact requirements

## E.1. Functional requirements

**Table E.1:** Functional requirements

| # | Requirement | Explanation | Challenge(s) addressed | Category |
|---|---|---|---|---|
| REQT 1 | The method must use data from M-Files, Relatics, and ACC, ensuring a unified approach to milestone tracking. | Interviews revealed that milestone-related data is fragmented across multiple systems, making retrieval inefficient. A centralized approach ensures data consistency and accessibility. | Process & Organization Related, Data & System Related | Functional |
| REQT 2 | The method should define milestones for the VO, DO, and UO phases. | Interviewees reported inconsistencies in milestone definitions across teams and projects. Standardization ensures uniform tracking and comparability. | Process & Organization Related | Functional |
| REQT 3 | The method should support the use of Key Performance Indicators (KPIs) to track milestone progress instead of manual updates. | Interviews showed that milestone tracking relies on meetings and subjective reporting, leading to inefficiencies. KPIs enable objective, real-time tracking. | Process & Organization Related, Data & System Related | Functional |
| REQT 4 | The method must incorporate early warning signals (EWS) that flag potential milestone delays based on predefined performance indicators. | Delays are often identified too late. Interviewees emphasized the need for proactive indicators that alert managers before disruptions occur. | Process & Organization Related, Data & System Related, Team Related | Functional |
| REQT 5 | A visual dashboard, potentially using tools such as Power BI, should provide a clear and intuitive overview of milestone progress. | Different disciplines use separate planning methods, causing coordination issues. A unified system ensures alignment. | Process & Organization Related, Team Related | Functional |

## E.2. System requirements

**Table E.2:** System requirements

| # | Requirement | Explanation | Challenge(s) addressed | Category |
|---|---|---|---|---|
| REQT 6 | The method must integrate with M-Files, Relatics, and ACC, avoiding the need for additional software/programs. | Current systems do not allow timely recognition of delays. Seamless integration supports proactive tracking. | Data & System Related | System |
| REQT 7 | The tracking system should support milestone coordination within and across different design disciplines. | Current milestone tracking lacks objective metrics. KPIs help provide measurable insights. | Process & Organization Related | System |
| REQT 8 | The method should automate milestone tracking and reporting, minimizing manual effort. | Teams struggle with retrieving milestone data, often relying on manual steps. Automation improves accuracy and saves time. | Data & System Related | System |
| REQT 9 | The method must be flexible enough to be applied to projects of varying sizes and complexity levels. | Resistance to digital tools is common. A scalable and adaptable system ensures broader adoption. | Process & Organization Related | System |

## E.3. Organizational requirements

**Table E.3:** Organizational requirements

| # | Requirement | Explanation | Challenge(s) addressed | Category |
|---|---|---|---|---|
| REQT 10 | The method should be intuitive and easy to use, allowing design managers and design leaders to adopt it without the need for training. | Interviewees emphasized that a new method should improve current processes without adding complexity. | Process & Organization Related | Organizational |
| REQT 11 | The method should ensure that information is presented in a clear and structured manner so users can quickly assess progress at a glance. | A major challenge is the lack of visibility. A clear presentation helps teams quickly understand project status. | Data & System Related | Organizational |
| REQT 12 | The method should minimize manual effort and integrate into existing workflows at Heijmans. | Current processes for retrieving data are inefficient. Integrating with existing systems ensures smoother adoption. | Process & Organization Related | Organizational |

# F

# Importance index KPIs

**Step 1: Importance index**
The interviews resulted a broad list of approximately 25 potential indicators. To identify those with the highest insight, an importance index was applied to rank the indicators based on expert feedback. This method prioritizes indicators according to their perceived relevance within the context of design management, making it particularly suitable for exploratory research. Although the sample size was limited, the importance index remains appropriate due to its focus on relative importance rather than statistical generalization.

Experts at Heijmans rated the level of insight each indicator provides into the design process using a 1 to 5 scale, where 1 indicated no insight and 5 indicated a high level of insight. These scores were converted into a 0 to 100 scale following the approach proposed by Zhang (2005), with the values 1 to 5 corresponding to scores of 20, 40, 60, 80, and 100, respectively. This enabled a consistent and transparent ranking of the indicators, forming the basis for selecting the most relevant metrics for each KPI group. The importance index is calculated using the following formula:

$$Importance index = I_i = \frac{20Ri1 + 40Ri2 + 60Ri3 + 80Ri4 + 100Ri5}{Ri1 + Ri2 + Ri3 + Ri4 + Ri5}$$

where:

- $I_i$ = importance index for the $i$th indicator,
- $Ri1$ = number of responses **”almost no insight”**,
- $Ri2$ = number of responses **”little insight”**,
- $Ri3$ = number of responses **”moderate insight”**,
- $Ri4$ = number of responses **”good insight”**,
- $Ri5$ = number of responses **”a lot of insight”**.

For example, for the indicator *”number of validation rounds”*, the importance index was calculated as follows:

$$I_i = \frac{(1 \times 20) + (40 \times 3) + (60 \times 5) + (80 \times 0) + (100 \times 1)}{1 + 3 + 5 + 0 + 1} = 54.0$$

**Table F.1:** Indicators from the interview results

| Indicators from the interview results | 1 | 2 | 3 | 4 | 5 | Importance Index | Rank within group | Overall rank |
|---|---|---|---|---|---|---|---|---|
| Bestandsgrootte | 4 | 5 | 2 | 0 | 0 | 41.8 | 7 | 25 |
| Check-in / check-out van documenten | 0 | 7 | 3 | 0 | 0 | 46.0 | 6 | 23 |
| Documentstatus | 0 | 1 | 2 | 4 | 4 | 80.0 | 2 | 6 |
| Documenten in the workflow | 0 | 2 | 6 | 2 | 1 | 63.6 | 3 | 13 |
| Documentplanning | 0 | 0 | 0 | 3 | 8 | 94.5 | 1 | 1 |
| Aantal validatieronden | 1 | 3 | 5 | 0 | 1 | 54.0 | 5 | 21 |
| Aantal documentversies | 0 | 3 | 5 | 3 | 0 | 60.0 | 4 | 15 |
| Aantal geverifieerde eisen | 0 | 0 | 2 | 4 | 5 | 85.5 | 1 | 4 |
| Aantal openstaande eisen | 0 | 0 | 2 | 4 | 5 | 85.5 | 1 | 4 |
| Identificatie van knelpunten | 0 | 1 | 4 | 3 | 2 | 72 | 4 | 11 |
| Mate van afstemming | 1 | 1 | 5 | 4 | 0 | 61.8 | 5 | 14 |
| Aantal wijzigingen | 1 | 3 | 4 | 2 | 1 | 58.2 | 6 | 17 |
| Aantal opmerkingen | 0 | 2 | 4 | 4 | 1 | 67.3 | 3 | 9 |
| Risicoprofiel | 0 | 4 | 4 | 2 | 1 | 60.0 | 3 | 16 |
| Aantal risico's voorzien van beheersmaatregelen | 0 | 2 | 5 | 2 | 2 | 67.3 | 1 | 10 |
| Aantal openstaande risico's | 0 | 2 | 5 | 2 | 2 | 67.3 | 1 | 10 |
| Aantal stakeholders betrokken in het project | 5 | 2 | 3 | 1 | 0 | 40.0 | 4 | 24 |
| Tijd per validatie | 3 | 3 | 1 | 3 | 1 | 52.7 | 5 | 18 |
| Doorlooptijd | 0 | 4 | 2 | 4 | 1 | 63.6 | 4 | 12 |
| Urenregistratie | 0 | 2 | 0 | 5 | 4 | 80.0 | 2 | 5 |
| Activity-based tracking | 0 | 0 | 3 | 6 | 2 | 78.2 | 3 | 7 |
| Lean planning | 0 | 0 | 1 | 2 | 8 | 92.7 | 1 | 2 |
| Frequentie van informatie uitwisseling | 0 | 3 | 6 | 1 | 0 | 50.9 | 6 | 19 |
| Uitwisselbaarheid van teamleden | 2 | 2 | 4 | 0 | 2 | 50.9 | 1 | 20 |
| Kritieke teamleden | 1 | 4 | 4 | 0 | 1 | 52.0 | 2 | 22 |

**Step 2: Data consistency and correlation**
To ensure reliability of indicators, responses for each of the indicators have been analysed for their standard deviations. A lower standard deviation indicates greater response consistency, suggesting the respondent group finds the indicator useful for different respondents

## Standard deviation calculation

The standard deviation for each indicator was calculated to assess the variability in the responses. The standard deviation is a measure of variability in a dataset. It should be mentioned, however, that this calculation is based on a small sample size (n=11) to analyze variability in expert responses. The decision to use a limited sample size aligns with the design of this research. The framework developed in the following chapter is intended for end users, making it relevant to gather data only from those who will actually use the framework. As a result, this limitation leads to a smaller sample size. However, the standard deviation (STD) is not intended to derive definitive statistical conclusions but rather to identify themes and patterns that may be useful in complementing other methods. The standard deviation is calculated using the following formula:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

where:

- $N$ is the total number of observations (responses),
- $x_i$ represents an individual response value (numerically converted from qualitative responses),
- $\mu$ is the mean of all responses,

- $\sum$ denotes summation over all responses.

If a KPI has low STD (range 0 - 0.5), then there are similar ratings from the majority of respondents. This indicates there's consensus on whether the KPI is useful or not. A moderate STD (range 0.5 - 1.0) indicates there's general consensus, with respondents' views being somewhat different. A high STD (range > 1.0) indicates respondents had varying views on the usefulness of the KPI. Some rated it highly, while others gave it a low rating.

### Scatter plot

The scatter plot will be used to evaluate the perceived usefulness of Key Performance Indicators (KPIs) in tracking design progress. By analyzing the relationship between mean scores and standard deviation, insights can be derived that guide the selection and refinement of KPIs for milestone tracking. The scatter plot consists of four quadrants that categorize KPIs based on their perceived usefulness and the level of agreement among respondents.

The bottom-left quadrant contains KPIs with low usefulness and strong agreement, indicating that most respondents consider these indicators ineffective. The bottom-right quadrant represents KPIs with high usefulness and strong agreement, making them the most reliable for milestone tracking. The top-left quadrant includes KPIs with low usefulness but high disagreement, suggesting that their value depends on specific project contexts. The top-right quadrant features KPIs with high usefulness but mixed opinions, indicating that while they are generally valuable, their application may vary based on factors such as project type or team structure.

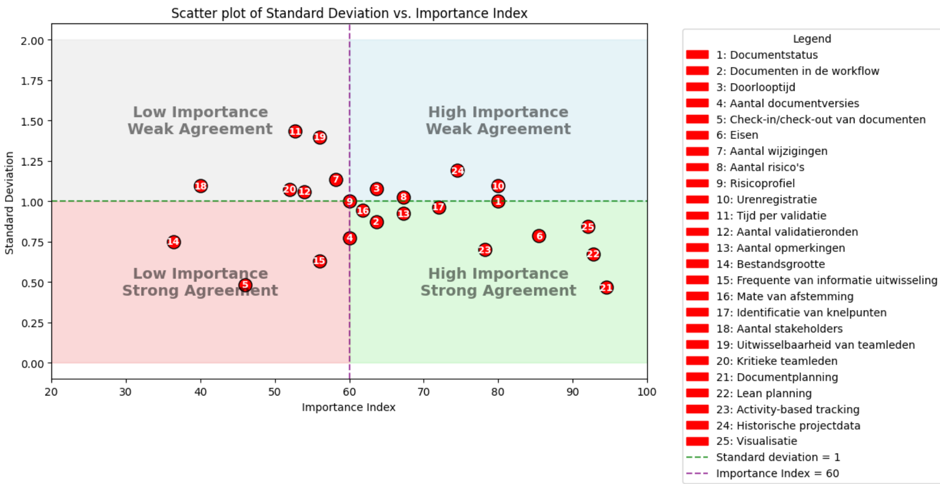



**Figure F.1:** Scatter plot of importance index vs. standard deviation

### Correlation matrix

The correlation plot was used to study the connections between different indicators, helping to find patterns and relationships in the data. Indicators that had strong correlations were seen as important because they show how multiple factors work together to provide a clearer picture than just one indicator alone. This approach also helps identify indicators that are too similar, making sure that each one adds unique value. Strong correlations can also reveal hidden trends or relationships within the system, leading to better decision-making. By grouping related indicators, this analysis ensures that the importance index reflects not just individual contributions but also the combined effects of key factors.

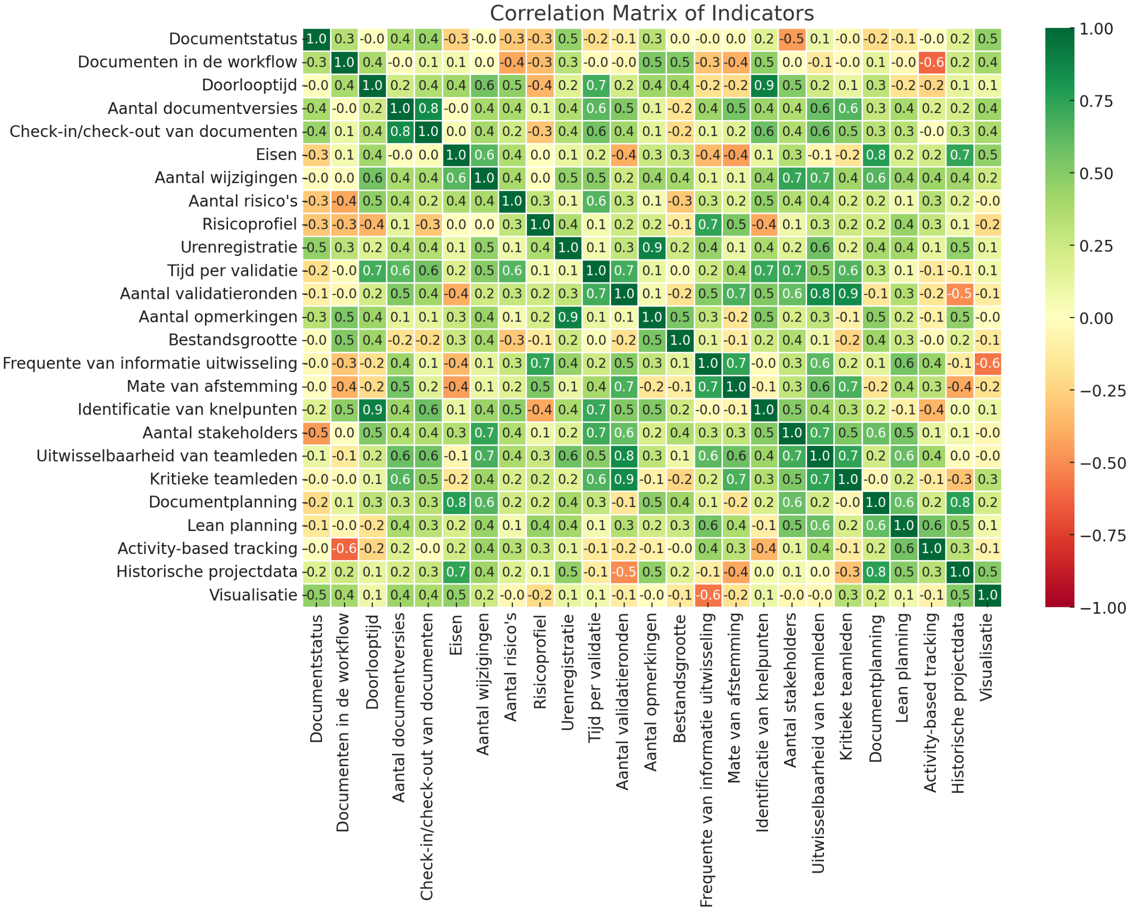



**Figure F.2:** Correlation matrix

# G

# Indicator measurement

## G.1. KPI 1: Management of document readiness

To measure this KPI group, the focus is on four indicators: *number of documents with a certain document-status*, *number of documents in the workflow*, *document-planning*, and *number of validation rounds*.

### 1.1 Document-planning (DPI)

The document-planning is used as indicator to track current progress vs. scheduled progress. This is expressed as a percentage that represents the cumulative number of deliverables completed relative to the number scheduled. A DPI of 100% indicates that the project is exactly on schedule, while a value above 100% means the project is ahead of schedule or that more documents are submitted compared to the number of documents scheduled, and below 100% signifies delays.

**Table G.1:** Indicator 1.1 – Document Planning Index (DPI)

| **Indicator** | **Document Planning Index (DPI)** |
|---|---|
| **Objective** | Evaluates how well the actual delivery of documents aligns with the planned schedule. A lower DPI may signal planning mismatches or workflow delays. |
| **Formula** | $$DPI(t) = \frac{D_{\text{actual}}(t)}{D_{\text{scheduled}}(t)} \times 100\%$$ |
| **Variable definitions** | • $D_{\text{actual}}(t)$ – Number of documents submitted by time $t$<br>• $D_{\text{scheduled}}(t)$ – Number of documents planned by time $t$ |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.1, table H.1. |
| **Time component** | Yes, possible to track daily, weekly or per milestone window |
| **Thresholds** | The thresholds are based on PPC benchmarks from the Last Planner System, where values above 95% indicate reliable planning performance (Ballard and Tommelein, 2021).<br>• Green: $\geq$ 95% – high reliability<br>• Yellow: 80–94% – minor delays, attention needed<br>• Red: $<$ 80% – critical delay, immediate action |

The flowchart in Figure 6.3 illustrates how indicator 1.1 (DPI) is measured and applied within the DPMT. It shows the full process: from data collection and processing, to calculating the DPI value, assessing its meaning, and taking follow-up actions when needed.

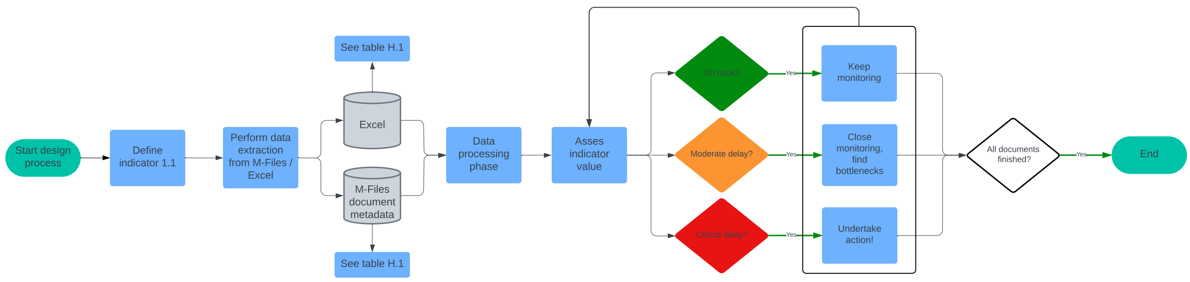



**Figure G.1:** Flowchart for indicator 1.1

## 1.2 Number of documents with a certain document-status (DS)

This indicator provides a detailed view of the status of documents at any given point in time throughout the project. It tracks how many documents are in each status (Planned, Draft, Verification, Authorization, Final, etc.) at every time step, allowing for a structured analysis of document progress.

**Table G.2:** Indicator 1.2 – Number of documents with a certain document-status (DS)

| **Indicator** | **Number of documents with a certain document-status (DS)** |
|---|---|
| **Objective** | Provides insight into the distribution of documents across workflow statuses (e.g., concept, review, approved). This helps assess design flow and whether documents are progressing toward final approval. |
| **Formula** | $$DS(t,s) = \sum_{d=1}^{N} \delta_{d,s}(t)$$ |
| **Variable definitions** | • $N$ – Total number of documents at time $t$<br>• $\delta_{d,s}(t) = 1$ if document $d$ is in status $s$ at time $t$, otherwise $0$ |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.1, table H.2. |
| **Time component** | Yes, possible to track daily, weekly or per milestone window |
| **Thresholds** | Thresholds are project-dependent but typically aim for 80–90% of documents to be in the 'review' or 'approved' state by mid-to-late design phase. Benchmarking against historical project could predict trends.<br>• Green: $\geq$ 80% in review/approved<br>• Yellow: 60–79% – moderate flow, monitor closely<br>• Red: $<$ 60% – risk of delay, requires intervention |

This flowchart shows how the distribution of documents across different statuses is used to detect delays or bottlenecks in the design process. Based on the share of documents in review or approved status, different actions are triggered to support progress monitoring and early intervention

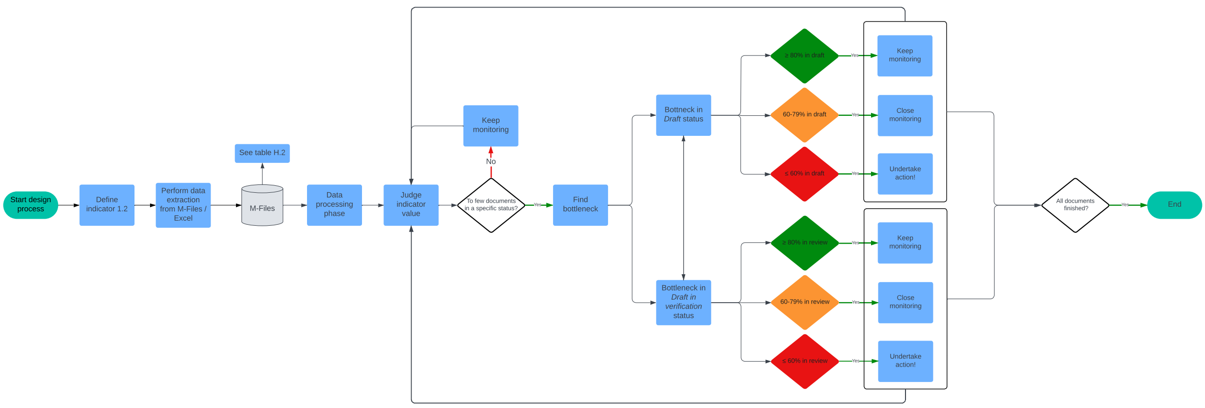



**Figure G.2:** Flowchart for indicator 1.2

### 1.3 Number of documents in the workflow

This indicator measures how frequently documents enter and exit workflows, providing insights into the overall activity of the document verification and approval process. Unlike the Document Status Distribution, which provides a static count of documents in different statuses at a given time, $AR_{workflow}$ tracks the dynamic movement of documents through the workflow system. It helps identify documents that are either stalling (low rate) or caught in iterative loops (high rate), supporting early detection of inefficiencies in the design process.

**Table G.3:** Indicator 1.3 – Action Rate for Documents in Workflow ($\text{AR}_{\text{workflow}}$)

| **Indicator** | **Number of documents in the workflow ($\text{AR}_{\text{workflow}}$)** |
|---|---|
| **Objective** | Monitor workflow efficiency by tracking the number of documents entering and exiting workflows within a defined time window. This helps detect stagnation, bottlenecks, or imbalance between document inflow and outflow. |
| **Formula** | $$AR_{\text{workflow}}(t) = \frac{1}{X} \sum_{i=t-X}^{t} \sum_{d=1}^{N} \left( \Delta W_{i,d}^{in} + \Delta W_{i,d}^{out} \right)$$ |
| **Variable definitions** | • $AR_{\text{workflow}}(t)$ – Average number of documents entering/exiting workflow per day over time window $X$<br>• $\Delta W_{i,d}^{in} = 1$ if document $d$ enters a workflow on day $i$; otherwise $0$<br>• $\Delta W_{i,d}^{out} = 1$ if document $d$ exits (reaches "Final") on day $i$; otherwise $0$<br>• $N$ – Total number of documents tracked<br>• $X$ – Length of time window (e.g., 5 days for weekly average) |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.1, table H.3. |
| **Time component** | Yes, calculated per rolling day or week |
| **Thresholds** | No strict threshold applies; interpretation depends on phase and project context. Thresholds or trends can be based on completed past projects.<br>• Typical baseline: 1–2 actions per document = expected progress<br>• $<$1 – indicates low activity, potential stagnation<br>• $>$3 – may signal rework, unclear requirements, or workflow issues |

Figure G.3 illustrates the operational logic for indicator 1.3. The flowchart begins at the start of the design process, where data from M-Files is collected and processed to compute the indicator. Based on the calculated AR value, the user identifies whether the activity level is within expected thresholds. If the AR is unusually low, the flow continues into an evaluation loop aimed at detecting stagnation, missing input, or lack of action. Conversely, if the AR is unusually high, the process should be checked for signs of rework or unclear requirements. In both cases, corrective actions can be undertaken, such as addressing bottlenecks or clarifying design expectations.

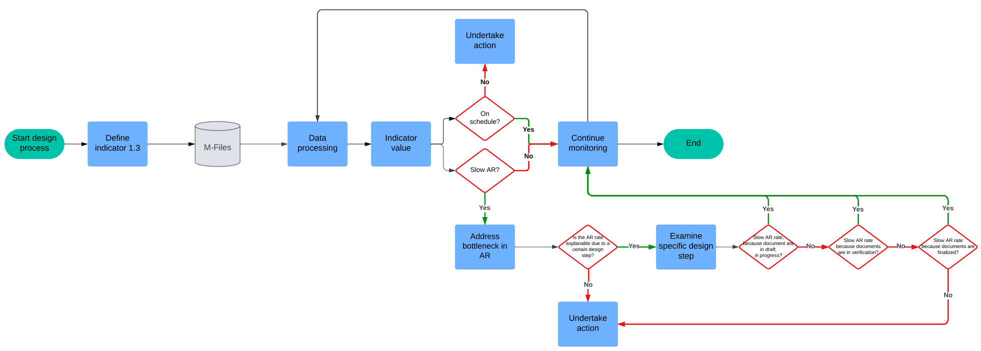



**Figure G.3:** Flowchart for indicator 1.3

## G.2. KPI 2: Management of requirements and changes

KPI 2 focuses on the management and control of project requirements and modifications to ensure that project goals remain aligned, disruptions are minimized, and the project progresses smoothly.

### 2.1 Number of verified requirements | 2.2 Number of open requirements

These two metrics give information about the requirements adherence progress of the project team. The count of verified requirements-the first of these- will tell how many requirements have been reviewed and found to meet the requirements of the project. It can be used to monitor how suitable the group is meeting objectives set for the design stage. The second indicator concerns the number of open requirements-those yet to be verified. Controlled opening numbers can avoid piling up unfinished requirements and later cause delays. Together, they tell the teams what has been completed with what still requires further focus.

**Table G.4:** Indicator 2.1 - Verified requirements

| **Indicator** | Verified requirements |
|---|---|
| **Objective** | Measures the total number of verified requirements per day. These indicator help assess overall verification progress and daily workflow consistency. |
| **Formulas** | $$VR(t) = \sum_{d=1}^{N} \left[\Delta V_d^{\text{verificator comply}} \times \Delta V_d^{\text{controller comply}}\right]$$ |
| **Variable definitions** | • $VR(t)$ – Total number of verified requirements at time $t$<br>• $\Delta V_d^{\text{verificator comply}} = 1$ if verificator judged *comply*, else 0<br>• $\Delta V_d^{\text{controller comply}} = 1$ if controller judged *comply*, else 0<br>• $N$ – Total requirements tracked<br>• $X$ – Time window in days (e.g., 5) |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.2, table H.4. |
| **Time component** | Yes, possible to track daily, weekly or per milestone window |
| **Thresholds** | Steady verification during the verification process; end-of-phase goal = 100% |

**Table G.5:** Indicator 2.2 - Open requirements

| **Indicator** | Number of Open Requirements (OR) |
|---|---|
| **Objective** | Tracks the total number of open requirements (not yet verified) at a given time. This helps teams avoid backlog and manage workload efficiently. |
| **Formula** | $$OR(t) = T - VR(t) + N$$ |
| **Variable Definitions** | • $OR(t)$ – Number of open requirements at time $t$<br>• $T$ – Total number of requirements in the project<br>• $VR(t)$ – Number of verified requirements at time $t$<br>• $N$ – New requirements added by the client |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.2, table H.5. |
| **Time Component** | Yes, possible to track daily, weekly or per milestone window |
| **Thresholds** | Goal is continuous reduction over time. End-of-phase goal = 0% |

## G.3. KPI 3: Management of risks

KPI 3 focuses on the management and control of risks throughout the design phase. Effective risk management ensures that potential disruptions are identified early, mitigation measures are implemented in a timely manner, and the project progresses with minimal unexpected setbacks. This KPI is essential for tracking how risks evolve over time, the effectiveness of mitigation strategies, and the overall impact of risk resolution on milestone adherence. The two primary indicators under this KPI are *the number of outstanding risks* and *the number of risks provided with mitigation measures*. These indicators provide insights into how well the project team is addressing and controlling risks that could delay milestone completion.

### 3.1 Number of outstanding risks

This indicator measures the total number of risks that remain unresolved at any given time. An increase in outstanding risks signals potential project instability, while a decreasing trend indicates that risk mitigation strategies are being successfully implemented. Outstanding risks are defined as risks that fall under one of the following statuses:

- **In overweging** (Under consideration)
- **Doorlopend** (Ongoing)
- **Wordt doorgevoerd** (Planned for implementation)

**Table G.6:** Indicator 3.1 – Number of Outstanding Risks

| **Indicator** | Number of Outstanding Risks |
|---|---|
| **Objective** | Tracks the total number of unresolved risks at a given time. A high or rising count signals possible instability, while a declining trend suggests active risk management. |
| **Formula** | $$R_{\text{outstanding}}(t) = \sum_{i=1}^{N} I_{\text{outstanding},i}(t)$$ |
| **Variable Definitions** | • $R_{\text{outstanding}}(t)$ – Number of outstanding risks at time $t$<br>• $I_{\text{outstanding},i}(t) = 1$ if risk $i$ has status "In overweging", "Doorlopend", or "Wordt doorgevoerd"; otherwise 0<br>• $N$ – Total number of identified risks |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.3, table H.6. |
| **Time Component** | Yes, possible to track daily, weekly or per milestone window |
| **Thresholds** | No strict threshold; key insight lies in the trend.<br>• Green: Decreasing trend<br>• Yellow: Plateauing or slow decline<br>• Red: Increasing risk count |

### 3.2 Number of risks provided with mitigation measures

This indicator tracks the number of risks that have been addressed through mitigation measures over time. A high value indicates that risk control efforts are effective, while a low or stagnant rate suggests that risks are not being resolved quickly enough. Mitigated risks are defined as risks that fall under one of the following statuses:

- **Is doorgevoerd** (Mitigation implemented)
- **Wordt niet doorgevoerd** (Mitigation not implemented)

**Table G.7:** Indicator 3.2 – Number of Mitigated Risks

| **Indicator** | Number of Mitigated Risks |
|---|---|
| **Objective** | Measures how many risks have been addressed through mitigation decisions. Indicates whether risk control actions are being implemented over time. |
| **Formula** | $$R_{\text{mitigated}}(t) = \sum_{i=1}^{N} I_{\text{mitigated},i}(t)$$ |
| **Variable Definitions** | • $R_{\text{mitigated}}(t)$ – Number of mitigated risks at time $t$<br>• $I_{\text{mitigated},i}(t) = 1$ if risk $i$ has status "Is doorgevoerd" or "Wordt niet doorgevoerd"; otherwise 0<br>• $N$ – Total number of identified risks |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.3, table H.7. |
| **Time Component** | Yes, possible to track daily, weekly or per milestone window |
| **Thresholds** | Progress is evaluated via increasing trend in mitigated risks.<br>• Green: Steadily increasing count<br>• Yellow: Slow or stagnant progress<br>• Red: No mitigation activity |

## G.4. KPI 4: Management of time tracking

KPI 4 ensures that design processes are executed within the planned timeframe by monitoring task durations, verification progress, and process adherence. Effective time tracking enables early identification of delays, improving design predictability.

The table below provides a comparison of the three verification indicators, highlighting their focus areas, key metrics, and objectives:

| Indicator | Focus Area | Key Metric | Objective |
|---|---|---|---|
| Verification Flow Efficiency (VFE) | Speed of moving from open to verified | Rate (requirements per unit time) | Measure how fast verifications are completed. |
| Verification Delay (VD) | Timeliness compared to the plan | Difference between planned and actual time | Detect whether verifications are early or late. |
| Average Verification Processing Time (AVPT) | Processing duration for each verification | Average time from submission to verification | Assess efficiency of verification handling. |

**Table G.8:** Comparison of Verification Indicators: VFE, VD, and AVPT

### 4.1 Verification flow efficiency (VFE)

Verification Flow Efficiency (VFE) measures the speed at which requirements move from the **"open"** status to **"verified"**. It represents the velocity of verification by calculating how quickly requirements are processed within the verification system.

**Table G.9:** Indicator 4.1 – Verification Flow Efficiency (VFE)

| | |
|---|---|
| **Indicator** | Verification Flow Efficiency (VFE) |
| **Objective** | Measures the velocity at which requirements transition from open to verified. It reflects how quickly requirements are processed through the verification workflow. |
| **Formula** | $$\text{VFE}(t) = \frac{\text{Number of Verified Requirements}}{\text{Time Taken for Verification}}$$ |
| **Variable definitions** | • Number of verified requirements – Total requirements verified during the period<br>• Time taken for verification – Time a document remained in verification status |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.4, table H.8. |
| **Time Component** | Yes – tracked per requirement and document |
| **Thresholds** | |

### 4.2 Verification delay ($VD$)

The **Verification Delay (VD)** measures the difference between the actual verification date and the scheduled verification date, indicating how early or late the verification was completed.

**Table G.10:** Indicator 4.2 – Verification Delay (VD)

| **Indicator** | Verification Delay (VD) |
|---|---|
| **Objective** | Measures the time deviation between actual and planned verification dates. A positive value indicates a delay; a negative value indicates early verification. |
| **Formula** | $$\text{VD}_j = T_{\text{ver},j} - T_{\text{planned},j}$$ |
| **Variable Definitions** | • $T_{\text{ver},j}$ – Actual verification date<br>• $T_{\text{planned},j}$ – Scheduled verification date |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.4, table H.9. |
| **Time Component** | Yes: calculated per verification instance |
| **Thresholds** | No treshold apply |

### 4.3 Average verification processing time ($AVPT$)

The **Average Verification Processing Time (AVPT)** measures the average time taken to complete verification after a document has been submitted. It provides insights into the efficiency of the verification process.

**Table G.11:** Indicator 4.3 – Average Verification Processing Time (AVPT)

| **Indicator** | Average Verification Processing Time (AVPT) |
|---|---|
| **Objective** | Measures the average time taken to verify documents after submission. This metric assesses the speed of the verification pipeline. |
| **Formula** | $$\text{AVPT} = \frac{\sum_{i=1}^{D_{\text{ver}}} (T_{\text{ver},i} - T_{\text{submitted},i})}{D_{\text{ver}}}$$ |
| **Variable Definitions** | • $T_{\text{ver},i}$ – Verification date of document $i$<br>• $T_{\text{submitted},i}$ – Submission date of document $i$<br>• $D_{\text{ver}}$ – Total number of verified documents |
| **Data inputs** | The specific data inputs, including their format, source system, and purpose, are detailed in appendix H.4, table H.10. |
| **Time Component** | Yes: measured in days |
| **Thresholds** | Based on the AVPT of historical projects |

# H

# Data structure overview of the indicators

## H.1. KPI 1

**Table H.1:** Data requirements for Indicator 1.1 – Document Planning Index (DPI)

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Document name | Text | M-Files | Unique identifier for tracking and joining |
| Planned completion date | Date | Excel / Planning tool | Defines deadline per document |
| Actual status change date | Date | M-Files | Marks actual document delivery date |
| Document status | Categorical (e.g., "Concept", "Final") | M-Files | Used to determine if a document is "done" |
| Phase (VO, DO, etc.) | Categorical | M-Files | Enables filtering per design stage |
| Reporting date $t$ | Date | Power BI filter | Used to compare actual vs. planned completions |

**Table H.2:** Data requirements for Indicator 1.2 – Document Status (DS)

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Document name | Text | M-Files | Track individual document status |
| Document status | Categorical (e.g., "Concept", "In review", "Final") | M-Files | Defines current state of a document |
| Status change date | DateTime | M-Files | Used to build time-series of status changes |
| Phase indicator | Categorical | M-Files | Enables filtering per design stage |
| Time period | Date range | Power BI | Slices the data for weekly/monthly reporting |

**Table H.3:** Data requirements for Indicator 1.3 – Action Rate for Documents in Workflow (ARworkflow)

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Document name | Text | M-Files | Links entries and exits to a specific document |
| Workflow event type | Categorical ("entry", "exit") | M-Files | Distinguishes type of workflow movement |
| Workflow timestamp | DateTime | M-Files | For calculating entry/exit frequency |
| Time window length $X$ | Integer (days) | Power BI parameter | Defines the temporal resolution |
| Total workflow entries in window | Integer (derived) | M-Files | Numerator in the action rate formula |

## H.2. KPI 2

**Table H.4:** Data requirements for Indicator 2.1 – Verified Requirements (VR) and Action Rate (AR)

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Requirement ID | Text | Relatics | Unique identifier to track requirement status |
| Verification status | Categorical (e.g., “Voldoet”, “Niet beoordeeld”) | Relatics | Indicates whether a requirement is verified |
| Verification date | Date | Relatics | Timestamp of successful verification |
| Phase (VO, DO, etc.) | Categorical | Relatics | Enables grouping by project stage |
| Verificateur (persoon) | Text | Relatics | Used for dashboards per reviewer |
| Number of actions per requirement | Integer (derived) | Relatics | Measures frequency of interactions |
| Timestamp of last action | DateTime | Relatics | Indicates recency of updates |

**Table H.5:** Data requirements for Indicator 2.2 – Number of Open Requirements (OR)

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Requirement ID | Text | Relatics | Unique ID for tracking verification status |
| Current status | Categorical | Relatics | Determines whether requirement is still open |
| Requirement type | Categorical | Relatics | Used for grouping (e.g., legal, technical) |
| Last update date | DateTime | Relatics | Supports age analysis of requirements |
| Linked document(s) | Text or Key | Relatics / Manual | Optional traceability to documents |
| Phase | Categorical | Relatics | Enables phase-wise reporting |

## H.3. KPI 3

**Table H.6:** Data requirements for Indicator 3.1 – Number of Outstanding Risks

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Risk ID | Text | Relatics | Identifier for tracking and reporting |
| Risk status | Categorical (e.g., “Actief”, “Afgesloten”) | Relatics | Defines whether a risk is still open |
| Last update timestamp | DateTime | Relatics | Enables monitoring of aging risks |
| Responsible person or role | Text | Relatics | For accountability tracking |
| Phase | Categorical | Relatics | Used to group risks per project stage |
| Linked document/component | Text / Key (optional) | Relatics / Manual | Optional linkage to relevant design items |

**Table H.7:** Data requirements for Indicator 3.2 – Number of Mitigated Risks

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Risk ID | Text | Relatics | Identifies resolved risks |
| Risk status | Categorical (e.g., “Mitigated”, “Afgesloten”) | Relatics | Determines if a risk is no longer critical |
| Mitigation date | Date | Relatics | Allows tracking mitigation over time |
| Risk type | Categorical | Relatics | Enables breakdown by category (design, cost, etc.) |
| Risk origin / milestone | Text / Tag | Relatics / Manual | Optional: links risk to specific event |

## H.4. KPI 4

**Table H.8:** Data requirements for Indicator 4.1 – Verification Flow Efficiency (VFE)

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Document name | Text | M-Files | Tracks workflow per document |
| Workflow entry event | DateTime | M-Files | Start of verification process |
| Workflow exit event | DateTime | M-Files | Completion of verification |
| Verification result | Categorical (e.g., "Voldoet") | M-Files | Indicates successful completion |
| Phase | Categorical | M-Files | Enables filtering by design stage |

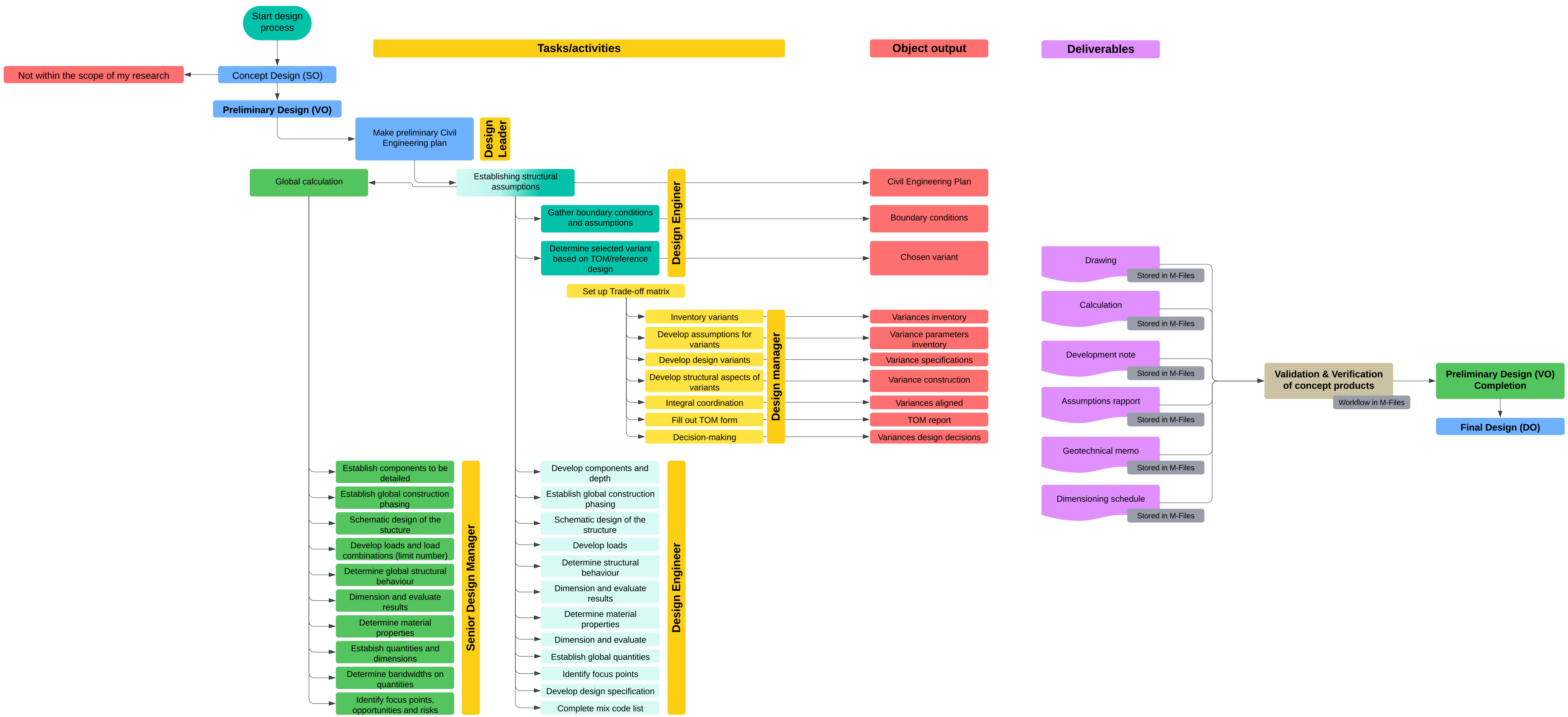
**Table H.9:** Data requirements for Indicator 4.2 – Verification Delay (VD)

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Document name | Text | M-Files / Planning Tool | Used to join planned and actual data |
| Planned verification deadline | Date | Excel / Planning tool | Establishes scheduled verification moment |
| Actual verification date | Date | M-Files | Records when verification was completed |
| Verification status | Categorical | M-Files | Filters completed verifications |
| Phase | Categorical | M-Files / Planning | Enables phase-specific delay reporting |

**Table H.10:** Data requirements for Indicator 4.3 – Average Verification Processing Time (AVPT)

| Data Input | Format | Source System | Purpose |
|---|---|---|---|
| Document name | Text | M-Files | Enables duration measurement per document |
| Workflow entry timestamp | DateTime | M-Files | Start of the verification cycle |
| Workflow exit timestamp | DateTime | M-Files | End of the verification cycle |
| Verification round number | Integer (optional) | Derived / M-Files | Enables per-cycle duration calculation |
| Phase | Categorical | M-Files | Enables phase-specific reporting |

# I
# Network diagram


Start design process
Tasks/activities
Object output
Deliverables
Not within the scope of my research
Concept Design (SO)
Preliminary Design (VO)
Make preliminary Civil Engineering plan
Design Leader
Global calculation
Establishing structural assumptions
Design Enginer
Civil Engineering Plan
Gather boundary conditions and assumptions
Boundary conditions
Determine selected variant based on TOM/reference design
Chosen variant
Set up Trade-off matrix
Inventory variants
Develop assumptions for variants
Develop design variants
Develop structural aspects of variants
Integral coordination
Fill out TOM form
Decision-making
Design manager
Variances inventory
Variance parameters inventory
Variance specifications
Variance construction
Variances aligned
TOM report
Variances design decisions
Drawing
Calculation
Development note
Assumptions rapport
Geotechnical memo
Dimensioning schedule
Stored in M-Files
Validation & Verification of concept products
Workflow in M-Files
Preliminary Design (VO) Completion
Final Design (DO)
Establish components to be detailed
Establish global construction phasing
Schematic design of the structure
Develop loads and load combinations (limit number)
Determine global structural behaviour
Dimension and evaluate results
Determine material properties
Estabish quantities and dimensions
Determine bandwidths on quantities
Identify focus points, opportunities and risks
Senior Design Manager
Develop components and depth
Establish global construction phasing
Schematic design of the structure
Develop loads
Determine structural behaviour
Dimension and evaluate results
Determine material properties
Dimension and evaluate
Establish global quantities
Identify focus points
Develop design specification
Complete mix code list
Design Engineer

# J

# Delay factors

Below, the key internal factors and their implications for the design process are outlined.

**Team capacity:**

- **Limited capacity:** A common issue is the lack of adequate team resources, which can be due to staff shortages, unavailability of team members, or personnel turnover. Not all team members work at the same pace or efficiency, which can impact the schedule.
- **Internal dependencies:** When team members or disciplines rely on each other, delays or disruptions from one party can affect the entire project.

**Team alignment:**

- **Communication challenges:** Poor communication among team members can lead to misunderstandings and delays. It is vital for team members to keep each other informed about their progress.
- **Interdependencies:** Designers often depend on input from other disciplines, and delays in one area can create a ripple effect. Effective communication of starting notes and essential information between disciplines is crucial.
- **Personal scheduling:** Overly optimistic individual planning by team members can lead to missed deadlines.
- **Lack of process discipline:** Failing to follow established procedures, such as document submissions, can cause delays.

**Coordination with execution:**

- **Feasibility issues:** If the execution team is involved too late in the process, the design may prove to be unfeasible, or alternative methods may be proposed, necessitating design revisions. Early involvement of the execution team is crucial to prevent such issues.

**Dependency on team members:**

- **Knowledge and expertise:** A lack of specific expertise within the team may lead to hiring less suitable external resources, potentially causing delays.
- **Absences or attrition:** Staff absences due to illness or other reasons pose risks to the schedule. The loss of team members with specialized knowledge can be particularly problematic.

# K

# Data-system connection within PowerBI

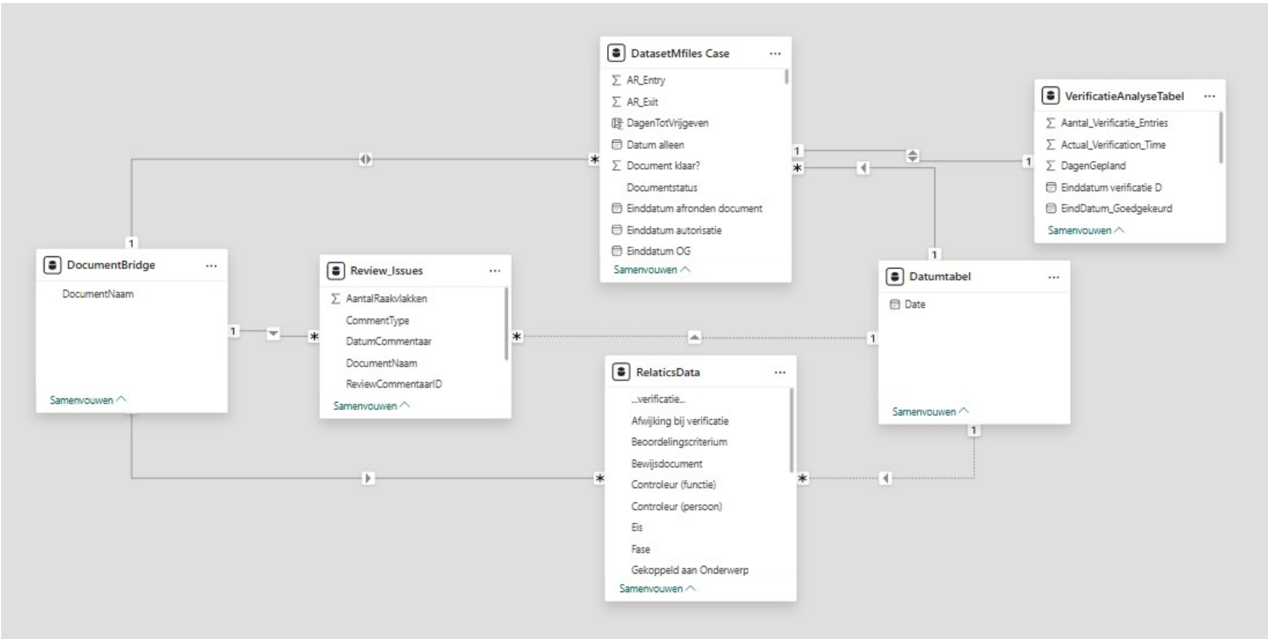



**Figure K.1:** System architecture within PowerBI

# L

# Conceptual DPMT

## Filters

WBS
Alle

SBS
Alle

Ontwerpfase
Alle

Documentnaam
Alle

Ontwerpperiode
3-11-2023 | 24-2-2025

TU Delft

heijmans

## Design Phase Monitoring Tool | Proof of Concept | Afstuderen Jeroen van Schaik

M1.1 - Deadline VO
afronding: 112 dagen

M2.1 - 23 dagen tot: Eerste ontwerp cycle (30% completed)

M3.1 - 37 dagen tot: Disciplinaire ontwerp afstemming

M2.2 - 64 dagen tot: Tweede ontwerp cycle (60% completed)

M2.3 - 83 dagen tot: Concept VO producten

M.4.1 - 86 dagen tot: Interne review VO

M.4.1.1 - 88 dagen tot: Verificatie D

M.4.1.1 - 95 dagen tot: Verificatie P

M3.2 - 101 dagen tot: Validatie van VO producten

M4.2 - 112 dagen tot: Deadline opdrachtgever

M1.2 - Deadline DO
afronding: 211 dagen

M2.1 - 143 dagen tot: Eerste ontwerp cycle (30% completed)

M3.1 - 157 dagen tot: Disciplinaire ontwerp afstemming

M2.2 - 181 dagen tot: Tweede ontwerp cycle (60% completed)

M2.3 - 195 dagen tot: Concept DO producten

M.4.1 - 196 dagen tot: Interne review DO

M.4.1.1 - 201 dagen tot: Verificatie D

M.4.1.1 - 206 dagen tot: Verificatie P

M3.2 - 207 dagen tot: Validatie van DO producten

M4.2 - 211 dagen tot: Deadline opdrachtgever

M1.3 - Deadline UO
afronding: 336 dagen

M2.1 - 256 dagen tot: Eerste ontwerp cycle (30% completed)

M3.1 - 270 dagen tot: Disciplinaire ontwerp afstemming

M2.2 - 293 dagen tot: Tweede ontwerp cycle (60% completed)

M2.3 - 315 dagen tot: Concept UO producten

M.4.1 - 320 dagen tot: Interne review UO

M.4.1.1 - 326 dagen tot: Verificatie D

M.4.1.1 - 330 dagen tot: Verificatie P

M3.2 - 332 dagen tot: Validatie van UO producten

M4.2 - 336 dagen tot: Deadline opdrachtgever

# Filters

WBS
Alle

SBS
Alle

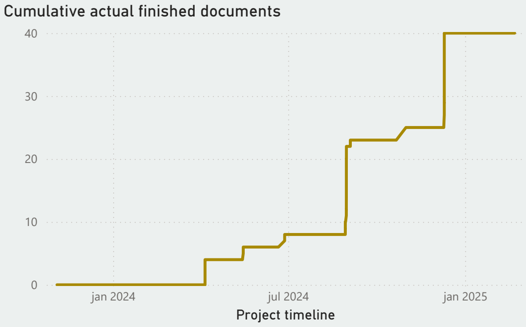
Ontwerpfase
Alle

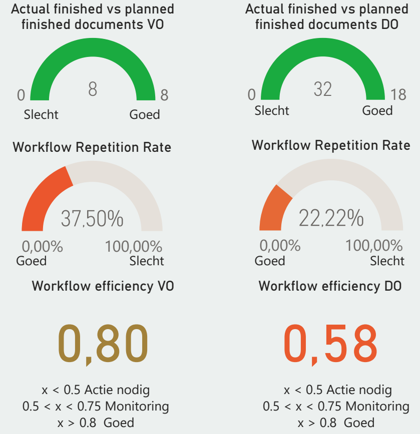
Documentnaam
Alle

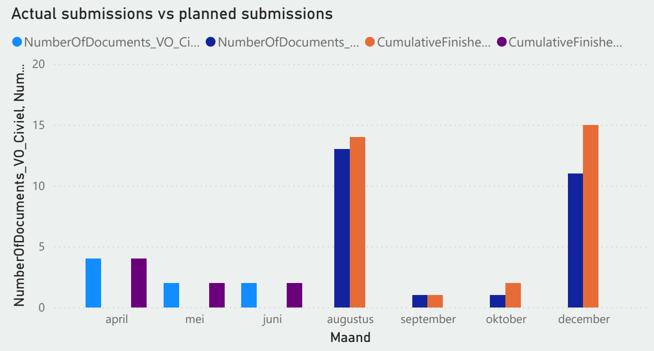
Ontwerpperiode
3-11-2023 — 21-2-2025

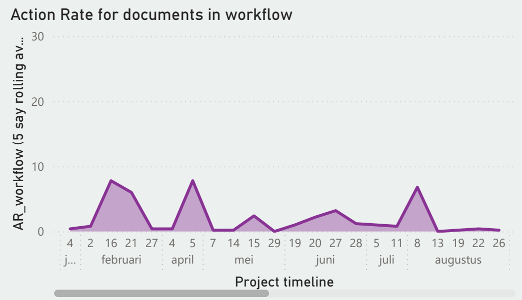
# Design Phase Monitoring Tool | Proof of Concept | Afstuderen Jeroen van Schaik

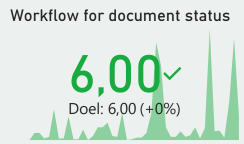
## KPI 1: Management of Document Readiness



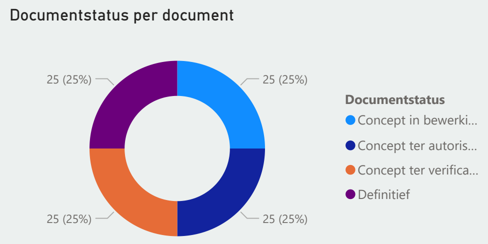



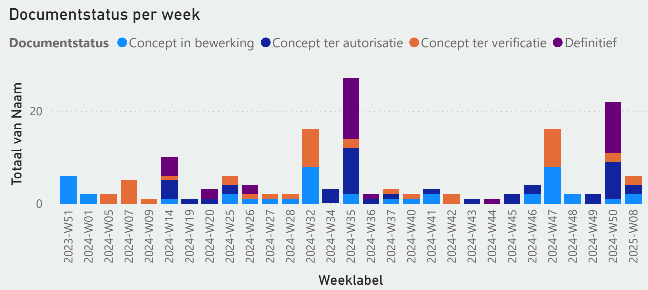



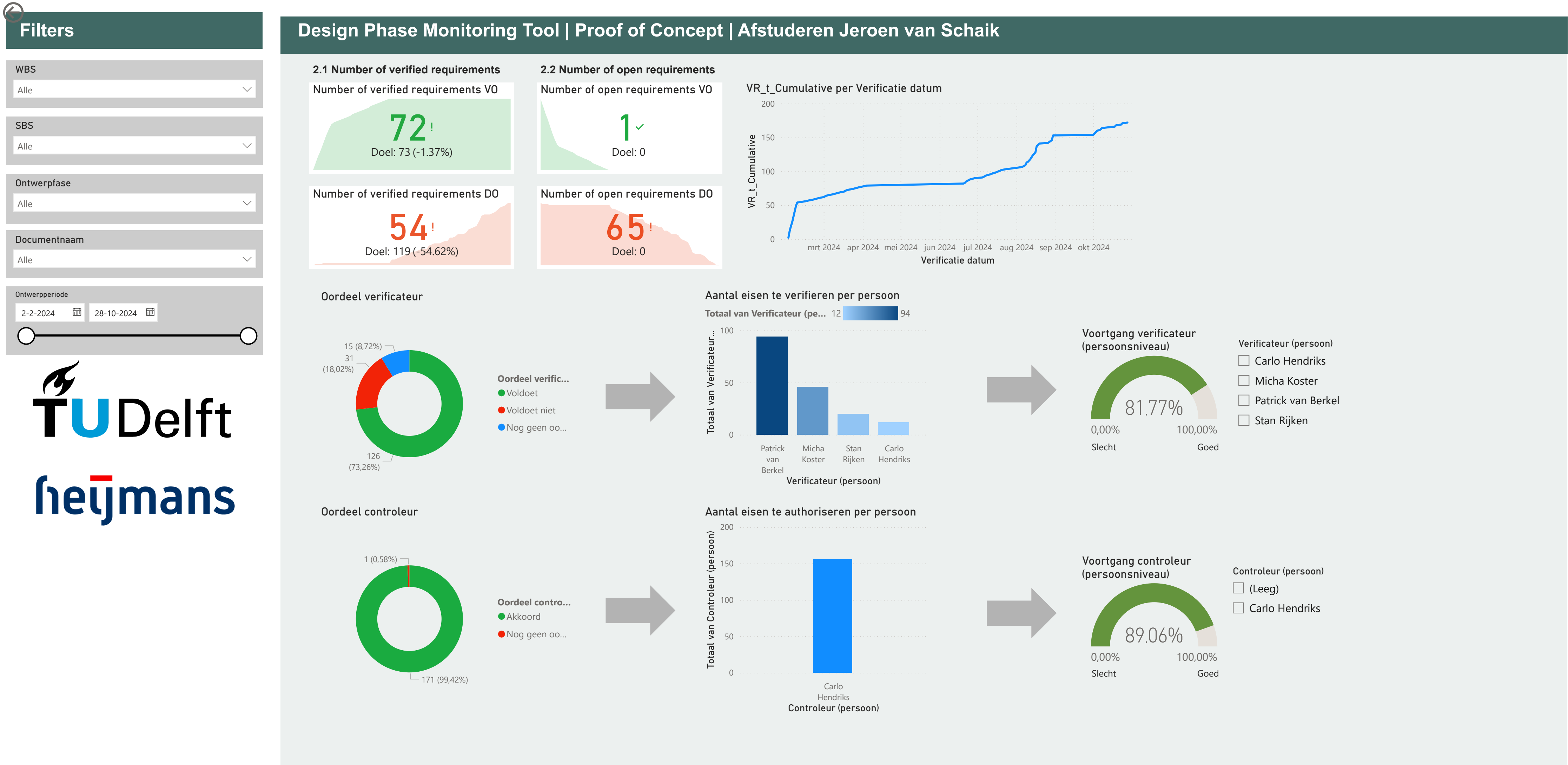

| Naam | Workflow_Efficiency_VO | Workflow_Efficiency_DO | Status Change (DS)? |
|---|---|---|---|
| VO-tekening KW1 ODG Graafseweg blad 2.pdf | 0,00 | | Changed |
| VO-tekening KW1 ODG Graafseweg blad 1.pdf | 0,00 | | Changed |
| VO-Ontwikkelnotitie KW1 ODG Graafseweg.docx | 0,00 | | Changed |
| VO-berekening KW1 ODG Graafseweg.docx | 0,00 | | Changed |
| Uitgangspuntenrapport Geotechniek.docx | 0,00 | | Changed |
| **Totaal** | **0,80** | **0,58** | |




Aantal documentwijziging van week tot week

792


Filters
WBS
Alle
SBS
Alle
Ontwerpfase
Alle
Documentnaam
Alle
Ontwerpperiode
2-2-2024
28-10-2024
Design Phase Monitoring Tool | Proof of Concept | Afstuderen Jeroen van Schaik
2.1 Number of verified requirements
2.2 Number of open requirements
Number of verified requirements VO
72 !
Doel: 73 (-1.37%)
Number of open requirements VO
1 ✓
Doel: 0
Number of verified requirements DO
54 !
Doel: 119 (-54.62%)
Number of open requirements DO
65 !
Doel: 0
VR_t_Cumulative per Verificatie datum
VR_t_Cumulative
200
150
100
50
0
mrt 2024
apr 2024
mei 2024
jun 2024
jul 2024
aug 2024
sep 2024
okt 2024
Verificatie datum
Oordeel verificateur
15 (8,72%)
31 (18,02%)
126 (73,26%)
Oordeel verific...
Voldoet
Voldoet niet
Nog geen oo...
Aantal eisen te verifieren per persoon
Totaal van Verificateur (pe... 12 94
Totaal van Verificateur...
100
50
0
Patrick van Berkel
Micha Koster
Stan Rijken
Carlo Hendriks
Verificateur (persoon)
Voortgang verificateur (persoonsniveau)
81,77%
0,00%
100,00%
Slecht
Goed
Verificateur (persoon)
Carlo Hendriks
Micha Koster
Patrick van Berkel
Stan Rijken
Oordeel controleur
1 (0,58%)
171 (99,42%)
Oordeel contro...
Akkoord
Nog geen oo...
Aantal eisen te authoriseren per persoon
Totaal van Controleur (persoon)
200
150
100
50
0
Carlo Hendriks
Controleur (persoon)
Voortgang controleur (persoonsniveau)
89,06%
0,00%
100,00%
Slecht
Goed
Controleur (persoon)
(Leeg)
Carlo Hendriks

## Input menu

WBS

- [ ] 04.02 Ontwerpen

SBS

- [ ] 03 - Langzaam verkeer onderdoorgang; 04 - ...
- [ ] 03.01 - KW1. Graafseweg

Product

- [ ] DO Civiel
- [ ] VO Civiel

Naam

- [ ] Calculatietekening KW1 ODG Graafseweg bla...
- [ ] Calculatietekening KW1 ODG Graafseweg bla...
- [ ] DO - KW1 - Berekening gesloten moot.docx
- [ ] DO - KW1 - Berekening keerwanden.docx

Ontwerpperiode

9-2-2024 21-2-2025

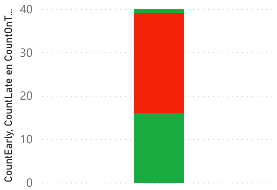
# Design Phase Monitoring Tool | Proof of Concept |

## KPI 4: Management of Time Tracking

### 4.1 Verification Flow Efficiency (VFE)

### 4.2 Verification Delay (VD)

CountEarly, CountLate en CountOnTime




16

CountEarly

1

CountOnTime

23

CountLate

| Naam | Planned enddate verification D | DateComparision | KPIStatusText | KPIStatus | Actual Verification D date |
|---|---|---|---|---|---|
| Uitgangspuntenrapport Betonnen Constructies.docx | 13-2-2024 0:00:00 | Early by 4 days | Early by 4 days | 1 | 9-2-2024 17:13:00 |
| Uitgangspuntenrapport Geotechniek.docx | 13-2-2024 0:00:00 | Early by 4 days | Early by 4 days | 1 | 9-2-2024 17:14:00 |
| Calculatietekening KW1 ODG Graafseweg blad 2.pdf | 23-2-2024 0:00:00 | Late by 41 days | Late by 41 days | -1 | 4-4-2024 12:00:00 |
| VO-Ontwikkelnotitie KW1 ODG Graafseweg.docx | 23-2-2024 0:00:00 | Late by 41 days | Late by 41 days | -1 | 4-4-2024 12:01:00 |
| VO-berekening KW1 ODG Graafseweg.docx | 5-3-2024 0:00:00 | Late by 12 days | Late by 12 days | -1 | 17-3-2024 23:54:00 |
| Calculatietekening KW1 ODG Graafseweg blad 1.pdf | 12-4-2024 0:00:00 | Early by 7 days | Early by 7 days | 1 | 5-4-2024 11:16:00 |
| VO-tekening KW1 ODG Graafseweg blad 1.pdf | 24-6-2024 0:00:00 | Early by 4 days | Early by 4 days | 1 | 20-6-2024 14:46:00 |
| DO - KW1 - Berekening pompkelder.docx | 26-6-2024 0:00:00 | Early by 1 days | Early by 1 days | 1 | 25-6-2024 15:28:00 |
| DO - KW1 - Geotechniek pompkelder.docx | 27-6-2024 0:00:00 | On time | On Time | 0 | 27-6-2024 11:12:00 |

### 4.3 Average verification processing time (AVPT)

6,93

AVPT_Planned

25,28

AVPT_Actual

AVPT_Actual en AVPT_Planned per Datum alleen