Master Thesis

A Framework for Developing Parametric Modeling Tools

A CASE STUDY OF WATER PUMPING STATIONS




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PREFACE

This document presents the a master thesis entitled:" A Framework for Developing Parametric Modelling Tools: A Case Study of Water Pumping Stations." The thesis represents the final requirement for the completion of the Master of Science in Construction Management and Engineering program, with a specialization in Digital Technologies in Construction, at the University of Twente. The research conducted in this thesis aims to provide a comprehensive understanding of the development process involved in creating a parametric model. The study was conducted over a period of six months and was commissioned by TAUW Nederland in collaboration with Wetterskip Fryslân. The supervisors, Mathieu Katier and Sven de Leau provided guidance and support on behalf of TAUW, while Farid Vahdatikhaki and Hans Voordijk supervised the research on behalf of the University of Twente.

I want to take this opportunity to express my gratitude to the individuals who have supported me throughout this six-month journey. First, I want to extend my appreciation to my supervisors from the University of Twente for their support and guidance during the research process. Although our interactions were limited, I reflected upon those moments with great satisfaction. Secondly, I am grateful to the team at Wetterskip Fryslân for their collaboration. This research would not have been possible without their shared data and knowledge. Thirdly, I would like to acknowledge my colleagues at TAUW for their inspiration, assistance, and motivation, which made my graduation research enjoyable and rewarding. Finally, I extend my heartfelt thanks to my TAUW supervisors, Mathieu, and Sven, for their unwavering support and guidance and for allowing me to undertake this research project.

Jasper Roest

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SUMMARY

Water pumping stations are critical assets within the water management system in the Netherlands. Many of these assets are due for replacement in the coming years. However, civil engineering profession is experiencing a scarcity of professionals, and factors such as an aging workforce contribute to the industry's difficulty in keeping up with digital transformation. Therefore, automating the process through the development of parametric modelling tools for water pumping stations may be a viable option. Parametric design is an iterative design process that utilizes underlying design algorithms driven by parameters.

This research developed a framework for the parametric modelling of civil structures resembling water pumping stations by creating a parametric modelling tool. Object-oriented modelling approaches were employed within this framework to understand the components and definitions comprehensively. The underlying design grammar and the sequential steps required to design a model corresponding to a detailed preliminary design level were examined. These steps were incorporated into the Gemalen Tool, which was developed and tested as proof-of-concept. The tool underwent validation rounds and a case study to assess its effectiveness. The findings revealed that a parametric modelling tool for water pumping stations is a feasible concept that enhances efficiency while remaining usable and functional. Therefore, the applied concepts can be a framework for developing other parametric modelling tools.

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ABREVIATIONS & TERMINOLOGY

Abbreviations	
AEC	Architecture, Engineering, and Construction
BIM	Building Information Modelling
CB-NL	Concepten Bibliotheek Nederland
CD	Continuous Deployment
CI	Continuous Integration
DevOps	Develop & Operate
LOD	Level of Detail
OBS	Object Breakdown Structure
OTL	Object Type Library
WF	Wetterskip Fryslân

Terms	Translation
Beschoeiing	*Revetment*
Bodembescherming	*Bottom Protection*
Elektronische Installatie	*Electronic Installation*
Fundering	*Foundation*
Gemaal	*Water Pumping Station*
Hekwerk	*Fencing*
Instroombak	*Inlet Reservoir*
Instroomconstructie	*Inlet Construction*
Instroomdek	*Inlet Deck*
Kast	*Box*
Krooshek	*Trash Rack*
Krooshekreiniger	*Trash Rack Cleaner*
Kroosleuning	*Trash Rail*
Kwelscherm	*Cut-off*
Leuningwerk	*Railing*
Luik	*Hatch*
Niveaumeetbuis	*Level Measuring Tube*
Ontluchting	*Vent*
Persleiding	*Presure pipe*
Pompinstalatie	*Pump Installation*
Poort	*Gate*
Slibschot	*Sludge Barrier*
Sponning	*Groove*
Terreinverlichting	*Lighting*
Terugslagklep	*Non-return Valve*
Uitstroombak	*Outlet Reservoir*
Uitstroomconstructie	*Outlet Construction*
Uitstroomdek	*Outlet Deck*
Verharding	*Pavement*
Vleugelwand	*Retaining wall*
Werktuigbouwkundige Installaties	*Mechanical Parts*

1 INTRODUCTION

In the Netherlands, more than five thousand water pumping stations of varied sizes were constructed between 1920 and 1960. Most of these structures are anticipated to be replaced in the next few decades. Waterboards possess ownership of most of these facilities and have assigned responsibility to manage and maintain them within their respective districts. Similar to construction consulting firms, waterboard institutions also engage engineers and designers who are accountable for designing as well as constructing water pumping installations. Engineers and designers are responsible for designing and supervising the implementation of water pumping stations, but they face challenges such as a shortage of workers in the industry and loss of knowledge due to an ageing workforce. The digital maturity within these organizations is low because older engineers and designers have difficulty adapting to modern technologies in a quick manner. In addition, waterboards must use financial resources responsibly since they operate in the public domain; therefore, high process efficiency should be prioritized. Unfortunately, this has not been achieved as each pumping station design requires significant effort despite its repetitive nature.

The issues outlined above can be addressed by automating the design process of water pumping stations. Given the repetitive nature of small water pumping stations, this process may be automated. A solution is to use parametric modelling tools. Parametric modelling tools use parameters and equations to design geometric shapes and structures. Successful implementation of parametric modelling has demonstrated numerous benefits, including increased efficiency, heightened accuracy, increased flexibility, and enhanced collaboration. However, more research must be done on parametric modelling in the construction sector and the parametrization of pumping station designs. Research can contribute to further developing and broadening knowledge about the use of these tools for pumping stations or other small civil structures. Therefore this master's thesis tries to develop a proof-of-concept for a parametric modelling tool that designs 3D model with a level of detail required for the preliminary design of a pumping station, in order to develop a framework for the creation of parametric modelling tools for similar structures.

This document serves as master thesis for completion of the master Civil Engineering and Management followed at the University of Twente. The master thesis research was conducted at TAUW in cooperation with Wetterskip Fryslân (WF). This master thesis research was under the supervision of Mathieu Katier and Sven de Leau on behalf of TAUW and Farid Vahdatikhaki and Hans Voordijk on behalf of the University of Twente.

1.1 Problem statement

The Netherlands is internationally perceived as a flat country with little height differences. However, if you look closely at the Netherlands, there certainly are height differences. Forty percent of the Netherlands is below sea level. Therefore, water management has historically been embedded in the identity of the Netherlands (STOWA, 2010). From the 15th century onwards, the Dutch started to drain land with wind energy-generated pumps. From around the year 1700 onwards, other power sources were used to actuate the water pumps for drainage. The first polders were created with these water pumps, and the drained land was transformed into fertile farmland. In later stages of the polder formation, land was created for human habitation (De Nederlandse Gemalen Stichting, 2023). With more than 2000 square kilometres of drained land, from 1950 till 1968 drained Flevopolder, is still the largest polder in the world (Loman, 2021). There are currently around 7800 pumping stations in operation in the Netherlands with a replacement value of 448 million euros (TNO, 2021). Despite the fact that the Dutch are managing the water for centuries, the battle against water continues. Due to climate change, the sea level is increasing, and intense rain showers and droughts are emerging more frequently. These alterations demand an amended approach for water management with pumping stations (Mol, 2021). Along with levees and dunes, pumping stations remain essential to Dutch water management, to ensure the Netherlands remain a liveable country.

Pumping stations are critical hydraulic infrastructure in the Netherlands. In earlier times, a significant amount of capital was invested in the development and maintenance of water pumping stations to create fertile agricultural land that could be inhabited. As these hydraulic structures age and are utilized more intensively over time, their ability to function effectively is compromised and they become economically inviable reaching the end of their operational lifetime (Bernardini, et al., 2014). On average water pump stations have a lifespan of about 50 years. Most of the hydraulic infrastructure, including pumping stations, was built between 1920 to 1960 making them bound for replacement within the next few decades. This major replacement assignment of the assets is called 'vervangingsopgave' in the Netherlands. Only in the province of Fryslân, more than 1000 pumping stations have to be replaced in the upcoming decades, of which 150 to 200 within the capacity range of 5 to 15 m3.

The replacement and renovation of all the pumping stations will pose a major challenge for the construction industry in the coming decades. The current shortage of materials and skilled labour, particularly civil designers, and water infrastructure experts, exacerbates the problem. According to research by de Ondernemer (2019), civil engineering designers is the most impaired function in the construction industry, with 73 percent of the vacancies remain open after two months. Furthermore, the ageing workforce in the industry will compound shortage of personnel. In 2021, 24 percent of the people working in the construction industry was between 55 and 75 years old, making the construction industry one of the oldest workforces in the Netherlands (ING, 2022). Due to digitalization and industrialization of the construction sector the scarcity of the labour market is increasing. Digitalization of design processes has the potential to increase productivity and improve the quality of delivered products in the construction sector, thereby mitigating the challenges of the water pumping stations replacement assignment (Aghimien, Aigbacboa, Oke, Thwala, & Moripe, 2020) & (Berlak, Hafner, & Kuppelweiser, 2020).

The recent advancements in technology with design automation holds great promise. Automation of design encompass the processes, tools and equipment used to design assets using automated workflows (PlanRadar, 2022). Compared to for instance the automotive and aerospace industries, the construction sector traditionally lags behind in adopting innovative technologies. However, employing design automation could potentially address problems encountered by this industry as identified earlier. The adaptation of parametric modelling presents a particularly promising avenue for automating designs. In parametric designing, geometric shapes are constructed by means of equations and parameters rather than defined solely through their structure or shape, providing an opportunity to automate laborious aspects of water pumping station design (Dzwierzynska & Prokopska, 2018). Parametrization of design in the construction industry is still relatively new as compared to its implementation in industries such as automotive and industrial sectors. The scale and complexity of design for construction projects are larger, introducing longer lead times alongside stakeholder involvement resulting in multiple iterations before finalizing a design. The conventional practice of designing water pumping stations has proved to be laborious since customized calculations and designs are created every time. However, given the repetitive nature of their design process, parametric modelling can offer an appropriate solution.

To conclude, the replacement assignment of pumping stations in the Netherlands will require significant engineering and design efforts. The construction sector currently lacks sufficient personnel with the necessary expertise of pumping stations, particularly in the area of civil construction design. Automation of the design process using parametric modelling tools could aid in meeting the replacement assignment needs. By outsourcing repetitive design tasks to modelling software, the overall design effort could be reduced. However, there is a lack of understanding on how to apply parametric modelling on pumping stations design. The lack of insights can be decomposed into two main parts: the core design parameters required for complete pumping stations design are unknown, and there is no established methodology for translating design parameters into a complete design of pumping stations that incorporates design grammar and constraints into a model. Developing a proof of concept can provide valuable insights and improve the application and advancements of such tools in a framework. A proof of concept must satisfy specific criteria for it to be usable, including increased efficiency, while remaining functional, and usable.

1.2 What is a water pumping station?

Before exploring the development of a parametric modelling system for water pumping stations, it is essential to establish a mutual understanding of what exactly a water pumping station is (referred to as "gemaal" in Dutch) and why it forms such an integral component of the water management infrastructure in the Netherlands. A water pumping station can be defined as: "an object which is essentially used to bring water from a low level to a high level, which may be necessary due to excess water on the low side(discharge) or water demand in the higher laying area(supply)" (Waterschap Hunze en Aa's, 2023). The principal functions of water pumping stations are: they pump excess water out of an area, regulate water levels, and enhance the water quality by the distribution of fresh water.

With an estimated number of over five thousand water pumping stations in the Netherlands, they are critical installations within the country's water management system (van Esch, TU Eindhoven, Spierts, & ATKB, 2013). These pumping stations play a crucial role in regulating and maintaining water levels to ensure safe residential areas and efficient agriculture. It has become possible to drain swampy areas and regulate water levels by proactively managing water levels. Pumping stations come in assorted sizes, from larger imposing structures that dominate the flat polder landscape down to smaller ones which may be less noticeable but equally important for effective water management across the country.

Water pumping stations are typically situated as part of a water barrier, which can be primary or secondary barriers. In the Netherlands, primary barriers protect against flooding from the North Sea, Wadden Sea, and major rivers such as the Rhine, Meuse, the Western Scheldt, Eastern Scheldt, the Ijsselmeer, the Volkerak-Zoommeer, the Grevelingenmeer, the tidal part of the Dutch IJssel and the Veluwerrandmeren. Secondary barriers, also known as regional water defences, encompass polder levees, barriers along regional rivers and canals; compartment dikes; sleeper dikes; ridge stream banks; foreland enclosures and summer embankments (STOWA, 2017).

Pumping stations can be distinguished by their location and the type of pumping equipment used. Table 1 lists the location-based type of water pumping stations in the left column. Types 1.1 and 1.2 are situated in the secondary barriers, as types 1.3 and 1.4 are located in primary water barriers. In the right column, the water pumping stations are listed based on the pumping equipment. The capacity of submersible pumps and shaft pumps is typically less than the other pump types listed in the right column, however, there is no clear distinction among them regarding their location (Bergman, 2003). For this research, a pumping station with a submersible pump was selected, which can be situated in a polder water pumping station. The types of pumping stations that fall under the category within the study are shown in bold in the table below.

Table 1: Water pumping station types

	Types based on Location		Types based on pump type
1.1	***Poldergemaal*** *(English: Polder water pumping station*	2.1	*Vijzelgemaal* *(English: Auger pumping station)*
1.2	*Boezemgemaal* *(English: Basin water pumping station)*	2.2	*Open Schroefpomp* *(English: Open screw pump)*
1.3	*Zeegemaal* *(English: Sea water pumping station*	2.3	*Gesloten Schroefpomp* *(English: Closed screw pump*
1.4	*Gemaal in Hoofdwaterkering* *(English: Water pumping station in main watershed)*	2.4	*Schroefcentrifugaalpomp* *(English: Screw centrifugal pump)*
		2.5	*Centrifugaalpomp* *(English: Centrifugal pump)*
		2.6	*BVOP*
		2.7	***Dompelpomp*** *(English: Submersible pump)*
		2.8	*Schachtpomp* *(English: Tubular casing pump)*

1.3 Research Objective & Research Questions

1.3.1 RESEARCH OBJECTIVE

Considering the issues discussed in the problem context, the following research objective is formulated for this thesis research:

The research objective is to develop a framework for parametric modelling of water pumping stations according to Dutch standards in order to improve the efficiency, which is functionally suitable and usable.

The research is centred around the development of a framework for creating a parametric model. To validate the framework, the following conceptualized step-by-step plan was followed. The study primarily concentrated on the components depicted in Figure 1. Through the development of a proof of concept for a parametric modelling tool for water pumping stations (Gemalen Tool), the framework was assembled to contribute to the research gap introduced in the introduction. Several techniques were applied and evaluated for their applicability in developing parametric modelling tool. Simply put, the parametric model can be created when it satisfies at least one of the needs. These needs are that the object must be iterative and frequently occurring, the design must be complex but not so complex that it becomes non-reproducible, optimization may be required, and flexibility is necessary during the design process. When choosing to create a parametric model, at least one of these needs must be present, presence of multiple needs increases the likelihood of achieving a proof of concept. Whether it becomes a proof of concept depends on whether it meets the predefined requirements or, in other words, criteria. These criteria must be present at a sufficient level to qualify as a proof of concept. The requirements will be operationalized in the subsequent part of this thesis.

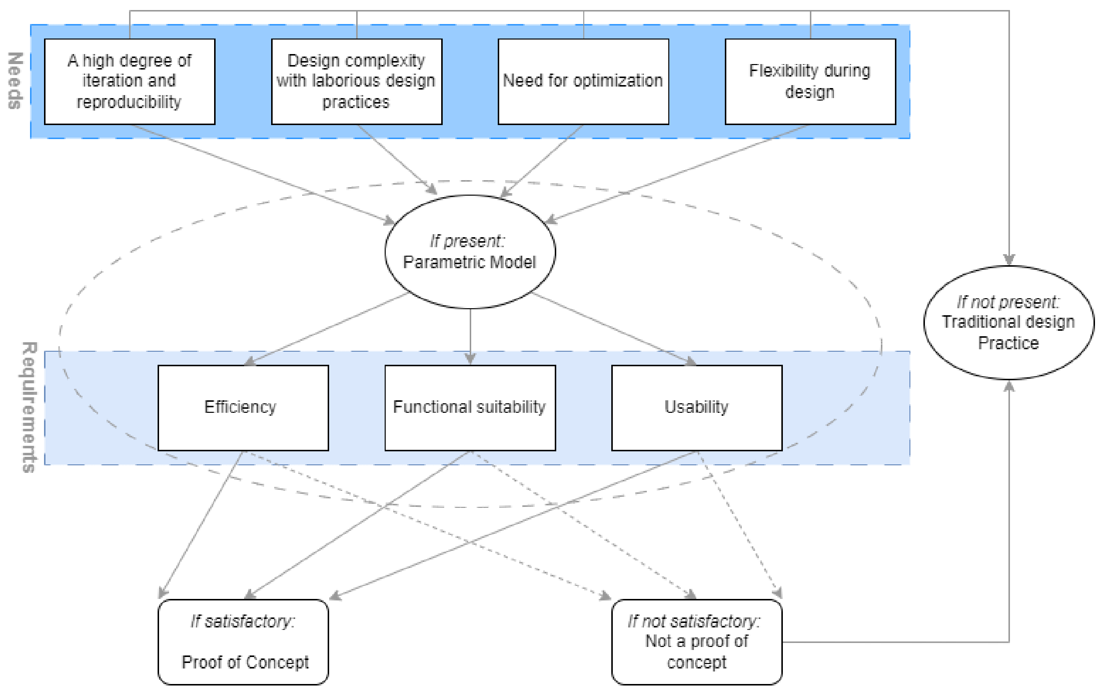

Figure 1: Conceptual set-up of the research

1.3.2 RESEARCH QUESTIONS

The aim of the research, as outlined in the preceding section, can be fulfilled by addressing the overarching research question, which has been derived from the context of the research and its desired outcome. The question is stated as follows:

How to develop a parametric model for the preliminary design of water pumping stations?

For answering the main research question, it is divided into several sub-questions as follows:

1. *What is the current, up-to-date (scientific) knowledge on parametric modelling tools, and what should be achieved by tools to ensure improvement of design practices in terms of efficiency while remaining functionally suitable and usable?*
2. *What is a pumping station, and what core parameters drive its complete design?*
    a. *How could a pumping station be decomposed in a mutual agreed Object Breakdown Structure (OBS)?*
    b. *What is the underlying design grammar, and how should it be conceptualized for it to be programmed with a minimal number of parameters?*
    c. *What is the evaluation of the traditional design practices of a pumping station based on the operationalized validation criteria?*
3. *How can the design grammar be transformed into programming code using the DevOps software development approach?*
4. *What is the validated outcome of a parametric modelling tool for pumping stations in terms of its proven concept status?*
    a. *To what extent was the applied methodology for developing the tool applicable to the development of parametric modelling tools?*
    b. *What actions can enhance the parametric modelling tool and its development methodology?*

1.4 Research scope

The initial stage of the technical design focuses on delineating the research scope. A proof-of-concept assessment is a feasibility study to demonstrate that a product meets its predetermined function and criteria. Prior to the research, criteria must be established in order to evaluate the feasibility and practicality of the final product. Therefore, part of this feasibility study is to develop the Gemalen Tool to a level where the criteria are met. The tool can be partially developed, but the foundation must be in place to determine whether the tool has the potential to be a success or not. Based on a discussion with TAUW and WF, the Gemalen Tool should increase efficiency while remaining usable and functional. The validation criteria will be further assessed in the validation strategy.

This study will conduct a proof-of-concept study specifically for pumping stations with a capacity of 5 to 15 m^3 per minute. This choice is grounded on the dissimilarities in design that can be attributed to the varying capacities of pumping stations. The type and size of the pump are decisive factors for the geometry and layout of a water pumping station. This analysis focuses on the 5 to 15m^3 per minute capacity range as it constitutes most of what can be found among pumping stations in the Netherlands. The research focuses on a specific type of water pumping station, known as the polder water pumping stations. These pumping stations are typically located in two fixed drainage level areas and transfer water from one polder to a basin with minimal fluctuation between both water levels. The submersible pump is the type of pump used in this study, which features an entirely submerged pump equipped with a waterproof motor that requires no physical structure for support. Additionally, its cooling systems rely solely on being immersed in the surrounding body of water rather than any external source or mechanism (Bergman, 2003). As discussed in Paragraph 1.2, water pumping stations in this range are typically situated in secondary water barriers.

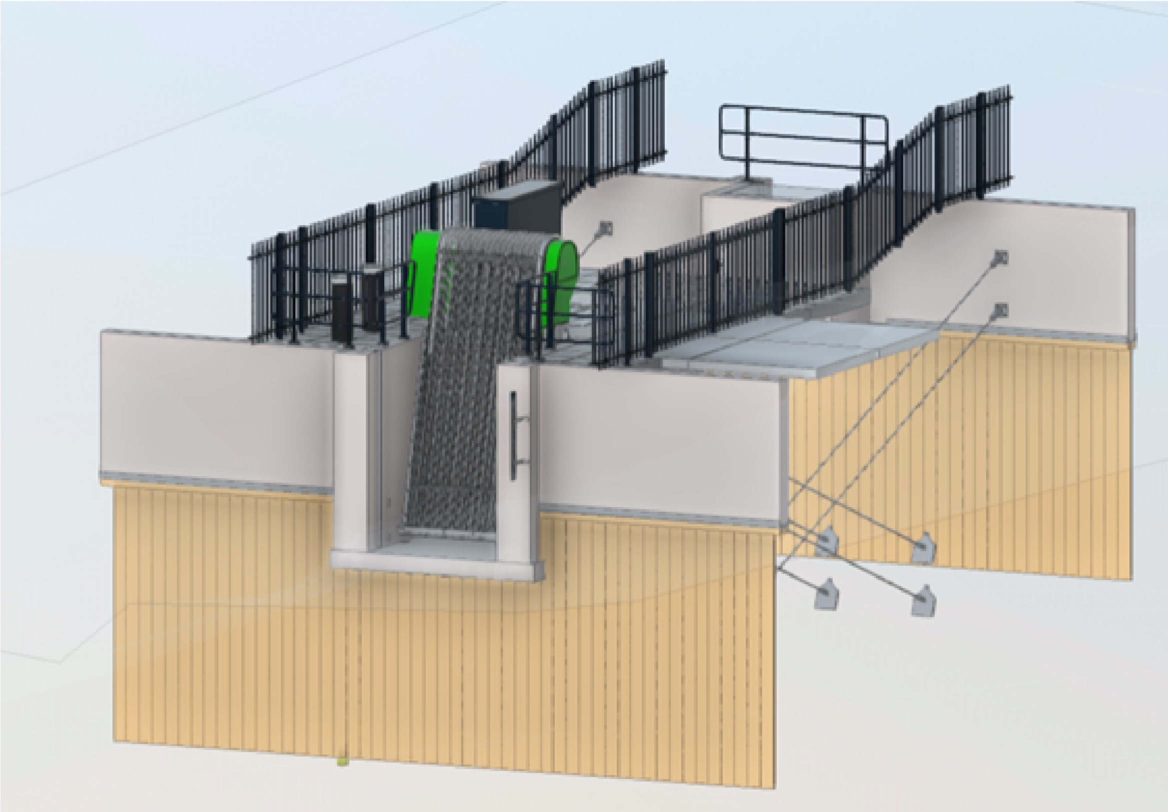

Figure 2: Example of preliminary design of pumping stations

The model had to generate a preliminary design output that closely resembles the level of detail(LOD) presented in Figure 2. Although there are no strict criteria for determining what constitutes a preliminary design, according to BNA (2014), its purpose is to create a comprehensive representation of the structure that offers a clear understanding regarding its location, functional and spatial arrangement, destinations, user amenities, architectural appearance, as well as the integration between structural elements and installation-technical aspects. The extent to which geometric details have been developed defines the LOD, an essential aspect in defining models and their requested precision levels. Consequently, it is crucial for the parametric model under development to comply with LOD 200 standards such that model elements represent certain systems/objects/assemblies concerning the quantity, size, shape, location, and orientation within the model itself. The BIM Forum has established LOD 200 standards as the minimum LOD required for the model creation of a preliminary design (BIM Forum, 2021). Their definition complies with the requirements of a preliminary design, as mentioned in: NEN 2574: fase Voorlopig Ontwerp, STB 2009: fase Voorontwerp, NEN 2660: Ruimte, Element, and NEN 2634: Elementclusters, Elementen Referentie Nl/SfB: Elementen, Variantelementgroepen. Nevertheless, a considerable portion of the components are replicated with even greater precision at LOD 250 or higher.

2 METHODOLOGY

As previously stated, there needs to be more understanding of developing a parametric modelling tool for pumping stations and the potential benefits it could bring. This study concentrated on determining the added value of the tool and exploring ways to develop a framework for developing a parametric model for water pumping stations. This chapter assesses the technical design of the research, including the methodology employed. Figure 3 provides a visualization of the research methodology, which is assessed for each phase individually in this chapter. The DevOps methodology has been applied to develop the parametric modelling tool, which is a collaborative software development practice that aims to bridge the gap between software development and operation teams. The DevOps methodology has been applied to maximize the overall efficiency of software development, which will be further explored through a literature review in Section 3.2.3.

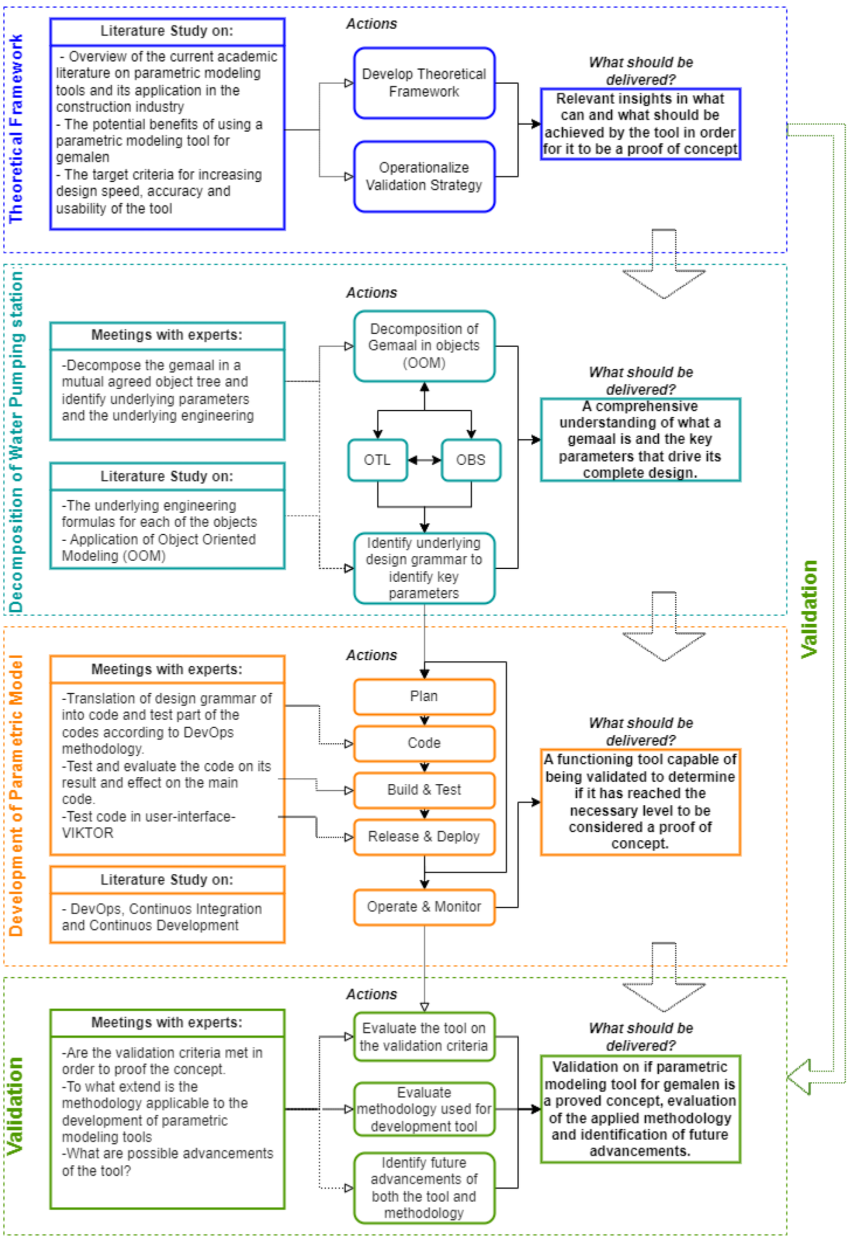

Figure 3: Conceptual Framework

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Throughout this research paper, references have been made to experts. The referred experts are individuals who are extensively involved in the operation of water pumping stations in their daily activities. Table 2 presents the different experts along with their areas of expertise. With the exception of supervisors Mathieu Katier and Sven de Leau, the identities of the other experts have been kept anonymous. All experts hold senior positions, indicating that they have more than five years of experience and possess in-depth knowledge in their respective fields. The experts are divided based on their employers. Within the WF organization, three out of the four experts are part of the core pumping station team. Their responsibilities include the design and implementation of all water pumping stations in the portfolio of WF.

Table 2: Water pumping station experts

Wetterskip Fryslân	Role
Anonymous	*Design Coordinator & Member of Core Team Water Pumping Stations*
Anonymous	*Design Coordinator & Member of Core Team Water Pumping Stations*
Anonymous	*Design Coordinator & Member of Core Team Water Pumping Stations*
Anonymous	*Structural Designer of Waterpumping stations*
TAUW	**Role**
Mathieu Katier	*Teammanager Ontwerpbureau & Program Manager Parametrization*
Anonymous	*Project Manager Specialized in Waterpumping Stations*
Anonymous	*Consultant Hydraulic Engineering*
Anonymous	*Project Manager & Consultant Hydraulic Engineering*
Anonymous	*Design Coordinator & Consultant Hydraulic Engineering*
Anonymous	*Design Coordinator*
Sven de Leau	*Structural Designer & Member of Steering Committee Parametrization(not participated in the validation phase)*

2.1 Theoretical Framework

Initially, the research commenced by conducting a thorough examination of existing literature. The purpose was to gather up-to-date and relevant information pertaining to parametric design, parametric modelling, and their utilization in the construction sector. In addition, the potential advantages associated with implementing such tools for water pumping stations were explored, alongside operationalizing the validation criteria. The first part of the literature review encompassed academic literature on parametric modelling tools and their applications, including the subjects of design automation, parametrization of design, and parametric modelling tools used in other industries. Secondly, the potential perquisites of using parametric modelling tools were identified through data collection on parametric modelling and design. The possible outcomes were used to define the validation criteria further. In addition, a literature study has been conducted on the subjects of Object-Oriented Modelling (OOM), Object Type Library (OTL), Object Breakdown Structure (OBS), and DevOps, which are methods that were used during the research. The final contribution to the theoretical framework involved gathering data on the three validation criteria, used to establish measurable criteria evaluated in phases two and four of the research. As shown in Figure 3, the first phase of the research consisted of collecting fundamental information about parametric modelling, the applied methods, and the operationalization of the validation strategy. This phase delivered relevant insights into what should be tested for the tool to be a proof of concept.

A semi-systematic literature review was applied to develop the theoretical framework of this research. A semi-systematic literature review aims to overview a research area and track development over time, describing the state of knowledge, themes in literature, historical overviews, research agendas, and theoretical models (Snyder, 2019). The literature was searched using the Scopus Web of Science and other databases listed on the University of Twente service portal. Besides scientific literature, informative websites were used to gather data on subjects that have yet to be extensively researched, such as parametric modelling tools in the construction industry. However, the formality of the content of the websites had to be verified. The same methodology was applied to the literature studies in other phases of the research.

2.2 Decomposition of water pumping station

The second part of the research consisted of decomposing a pumping station into several main- and sub-objects and identifying the design grammar of a water pumping station. The decomposition of the pumping station was checked and discussed with experts from both TAUW and WF. Together with de experts, the underlying reasoning, calculations, and dependencies were classified for all the subcomponents. OOM has been applied to decompose the water pumping station in objects. This included the creation of an OTL with a corresponding OBS. After decomposing a pumping station in objects, the underlying design grammar had to be researched to identify the core parameters required to deliver a complete design. A specialized literature study and expert meetings with engineers knowledgeable about water pumping stations examined the fundamental design grammar.

2.2.1 DEVELOPMENT OTL & OBS

The decomposition phase involved the separation of the assembly of a water pumping station into individual objects or components, which are essential for implementing OOM, OBS and OTL (Kennisconsult, 2014). The decomposition phase consisted of three stages: the development of a general OTL and OBS, the discussion of general OTL and OBS with experts at TAUW and WF, and the creation of an OBS and OTL tailor-made for the water pumping stations within the scoped range. The NEN 2767-4 methodology has been applied for the decomposition phase. The OOM, OTL and OBS methodologies are assessed in more detail in Section 3.2.3.

To apply OTL and OBS to the decomposition process, it was necessary to standardize the object definitions to ensure a comprehensive understanding of the objects within the water pumping station before the decomposition began. In order to define the standardized object definitions, a literature study was conducted on the general components of a water pumping station. The object definitions were also listed to create a comprehensive mutual understanding of the components, a prerequisite for the expert meetings at TAUW and WF. Furthermore, research was conducted on existing OBS's of water pumping stations in general. The OBSs often came with a corresponding OTL. Waternet had already established an OTL and OBS for a polder pumping station in general, which overlapped with the scoped range of water pumping stations, including a standardized definition of a pumping station and a subdivision of objects (Waternet, 2023). The OTL and OBS of Waternet, supplemented by other sources, were discussed during the meetings with water pumping stations experts at TAUW in order to come to an OBS and OTL for the water pumping stations within the predetermined capacity range in the acreage of WF.

2.2.2 INDENTIFICATION OF KEY PARAMETERS

After a comprehensive determination of the objects of water pumping stations within a predefined range, a detailed assessment was conducted to examine them further. This involved evaluating the design parameters, location, and connections to other elements for each element and object, to gain insight into the design principles underlying the water pumping station. To facilitate this assessment, WF provided three models of water pumping stations falling within the predefined range; each model was meticulously evaluated to analyse the design characteristics specific to water pumping stations. Subsequently, similarities among the models were identified to assess the level of standardisation in the design practices employed by WF. A civil designer of WF has checked the correctness of these standardisations. A customised comprehensive OTL was developed to capture the identified objects, definitions, reference images, variables, and locations. The definitions were established based on OTL data from reputable sources such as Waternet, and reference images or sheet was created utilising existing standard drawings from WF, and drawings retrieved from existing Revit models. In some instances, adjustments were made to the standard drawings to align them with the assumed standards applicable to WF, while others remained unchanged. The drawings obtained from the Revit models included a 3D overview and 3D detail representations, as well as 2D images indicating the variables involved. The variables were then individually elucidated, considering their dependencies on other variables and whether they adhered to the standards prescribed by WF. Finally, the location of the elements of the water pumping station were determined relative to the main elements and the overall structure.

Once the variables for each component had been identified, the next step was to determine the parameters and design grammar underlying the design. By understanding the interdependencies between the variables, the logical sequence of the design process was established, which could then be translated into a development plan for the tool. This plan is similar to the stages followed in the traditional design practices, such as those outlined in the "Bouwprocess: Beschrijving van het bouwproces voor opervlaktewater gemalen" (TAUW, 2011). This document involves a detailed description of the traditional design and construction processes of water pumping stations. For the development of a preliminary design for a water pumping stations, the document suggests the following main steps: 1) hydraulic design of the wet path, 2) determination of mechanical equipment, and 3) determination of civil structures adapted to the dimensions of the wet path and mechanical equipment. In addition, location-related parameters are important since they determine the location of the water pumping station in the landscape. The order of design as indicated by the "Bouwprocess: Beschrijving van het bouwproces voor oppervlaktewater gemalen," are the fundamentals of the Gemalen Tool.

2.3 Development of the parametric modelling tool

After the identification of the components of the system and the underlying design grammar, the next phase included the development of the tool. As already introduced shortly, the methodology applied for the development of the tool is the DevOps methodology. DevOps will be assessed in more detail in the theoretical framework. DevOps is a fusion of development and operation consisting of eight components, namely, plan, code, build, test, release, deploy, operate, and monitor (Leite, Rocha, Kon, Milojicic, & Meirelles, 2019). DevOps is a methodology where code is developed in collaboration with experts in small iterative circles. In these iterative circles, the code is created and checked until it reaches the intended level of detail before being added to the main software code. During the development of the tool, the following software programs were utilized: Viktor, Visual Studio Code, Git(hub), Revit, and Dynamo. Paragraph 2.3.3 provides a more detailed clarification of the software. The allocation of the software and other resources of each stage of the development of the proof of concept is displayed in Figure 4. In the remainder of this paragraph, the method will be specifically explained for each step of the DevOps methodology. Operate and monitor are not included in this project, since the project is limited exclusively to the development of the tool. The operate and monitor phase is comparable to the validation phase, which will be assessed in section 2.4.

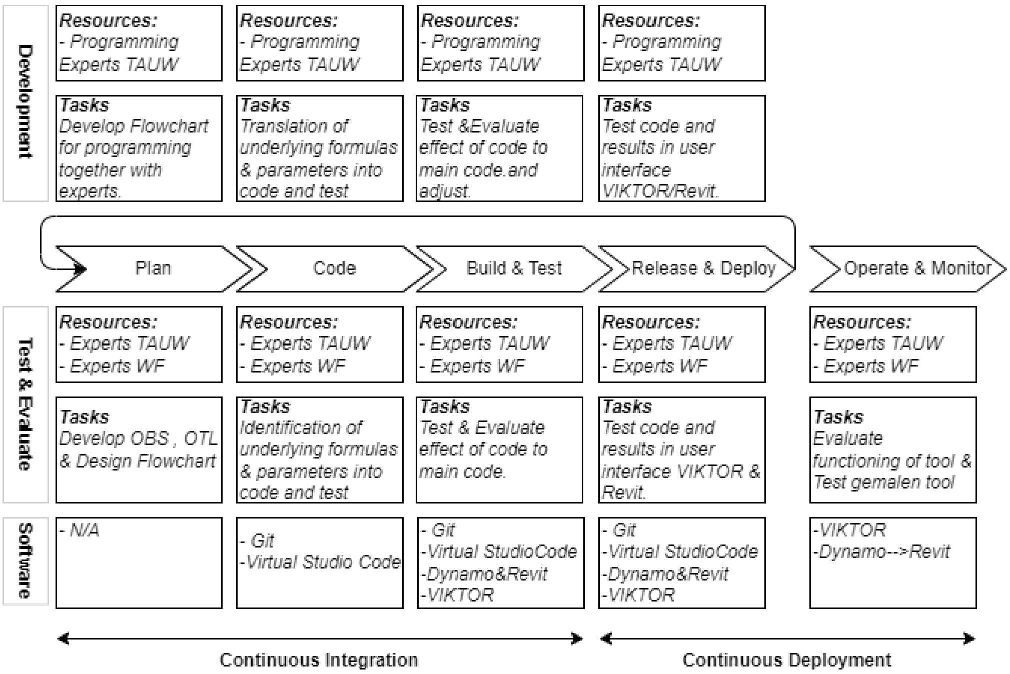


Figure 4: Allocation of Software and other resources

2.3.1 DEVOPS: PLAN

The Plan or Planning phase of DevOps involves the identification of key components of the tool. These components primarily pertain to the inclusion of objects within the tool and the design of a user interface that allows for parameter implementation, enabling the object to be modelled in a parametric manner. It was unnecessary to incorporate all elements into the model in order to achieve a preliminary design. Due to time constraints during the research process, not all elements were added to the model, and those included may not be fully parametric. A comparison between the actual objects incorporated in the model and the intended objects of the parametric model will be presented in the discussion in Figure 28.

The second aspect of the planning phase involved determining the extent to which the design grammar had to be represented in the model and how users could adjust the parameters. Crucial parameters must be inputted into an interface to achieve parametric modelling of the components. The crucial parameters correspond with the parameters identified in the decomposition phase. The parametric modelling software that is used for the development of the tool is VIKTOR. VIKTOR is discussed in more detail in Section 2.3.3. User stories were also formulated to facilitate model adjustments. These user stories provide a textual representation of the tool's desired input and the corresponding output. They were developed based on the researchers' interpretation, WF's desired inputs and outputs, and expert meetings at TAUW. To minimize the potential for user errors, input values are constrained by setting minimum and maximum values or providing pre-selected options. Visualizations are considered crucial, and overview sheets are incorporated into the user interface. Lastly, it is important to enable users to review and verify their actions.

2.3.2 DEVOPS: CODE, BUILD & TEST, AND RELEASE & DEPLOY

Code, Build & Test, and Release & Deploy are integral parts of the iterative inner circle of the DevOps methodology. The development of the model can be divided into three main components:

The development of the model can be divided into three main components:

- The development of the user interface in VIKTOR
- The transfer of output data from VIKTOR to the Revit model using Dynamo
- The creation of parametric modelled objects that dynamically change according to the parameter input

These components were developed sequentially, with the user interface capturing the foundational data, followed by modelling the main fixed components of the parametric model. Once a model based on the user interface data was established in Revit, the software development proceeded iteratively, with adjustments to the user interface based on the required information for parametric model development. This paragraph will briefly cover each of the three phases. The undertaken development steps have been visualized in Figure 5.

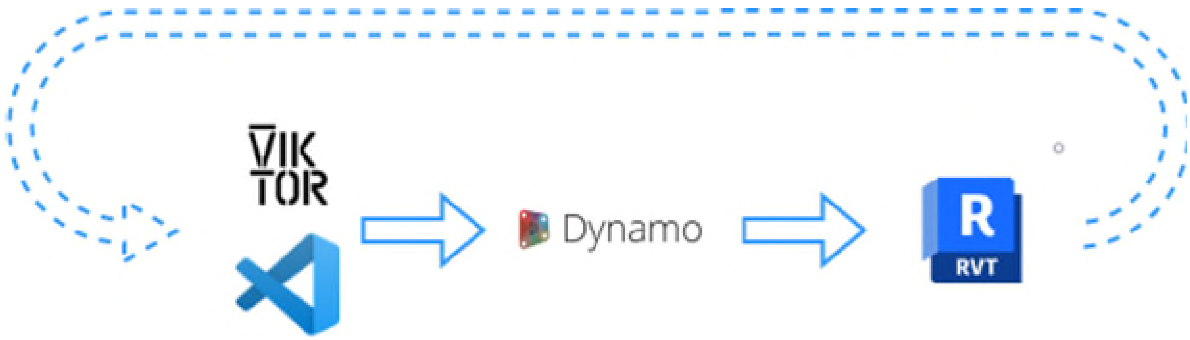


Figure 5: Development Scheme

The initial step in developing the parametric model involved the creation of a platform where parameters can be inputted. At TAUW, VIKTOR is utilized as the software for developing the parametric model. VIKTOR is a web-based interface controlled by Python language-capable software, with Visual Studio Code (VSC) employed for the tool's development. The tool's user interface development plan included user stories that defined the minimal input required for users to obtain the necessary data for model development. The specific objects within the model were determined based on the OTL, OBS and meetings with experts from TAUW and WF. The Gemalen Handbook and the document Bouwproces Gemalen of TAUW served as a reference for the logical sequence of design stapes, which became the foundation of the tool, dictating the order of parameter input and processing (Bergman, 2003)) & (van Raaij, 2011). The primary objective of the user interface was to minimize the number of parameters required to generate a model with the level of detail expected for a preliminary design. This approach necessitated extensive data processing in the background to derive the necessary dimensions. The input for the design was based on the current practices at WF, where fillable Excel sheets are used for water pumping stations design. The user interface processes this data in the background and utilizes it to generate relevant output in order for it to be used in Dynamo.

Dynamo is a visual programming platform that utilizes code blocks to execute specific functions. This research translates the input parameters into a 3D model in Revit. After producing a model in Revit based on the interface data, the tool was gradually refined. Iterative development steps were undertaken and extensively tested to align with the desired goals. In traditional DevOps practices, each notable change should be committed to the main code. However, since this product was developed by a single individual, the code was not always committed but stored locally. Periodically, a commitment was made to allow the supporting software developers at TAUW to review and make necessary adjustments to the code. Commits track changes and manages versions through Git. Major revisions to the code were always committed, enabling the ability to revert to previous versions when needed. As the tool was consistently saved in a functional state, the use of commits was not essential. The user interface also aimed to make the Gemalen Tool User-friendly and dummy-proof, preventing users from making mistakes. This approach enhanced usability and functionality, requiring less specialized knowledge than to traditional model creation methods.

2.3.3 SOFTWARE PROGRAMMES USED

VIKTOR-VIKTOR is a web-based platform that utilizes the low-code development approach to enable engineers to construct and disseminate user-friendly web applications with Python programming language. Low-code development generates an application using graphical interfaces instead of long coding lines. With its foundation in Python, VIKTOR offers programmers the optimal solution for producing parametric designs effectively. The ease-of-use characteristic of VIKTOR, coupled with comprehensive documentation, allows users to develop their tool seamlessly by leveraging broad functionalities accurately documented in a library alongside explicit corresponding Python codes furnished, and coming along with supported functions.

Visual Studio Code (VSC)-Visual Studio Code (VSC) is a powerful source code editor that offers multi-language compatibility and can facilitate the programming of various applications. In developing the Gemalen Tool program in VIKTOR, Python language code was written on VSC's integrated development environment. Various tools are incorporated in VSC, including debugging tools and syntax highlighting. Furthermore, its open-source version control system incorporated Git, which allows updates of source code by committing changes made within the editor itself; as a result, all updates were reflected in updated versions available on the Git repository smoothly.

Revit-Autodesk Revit is a Building Information and Modelling software application that facilitates the creation of 3D designs by engineers, architects, designers, and contractors. Users can add details in 2D while simultaneously subtracting information from the 3D model. Initially developed to design residential buildings and utility structures, its scope has expanded beyond these areas into civil engineering projects. Although widely utilized among professionals within each respective industry, Revit's capabilities require appropriate management of its abundance intensity of data through proper manipulation techniques to fully realize their potential benefits, including increased efficiency in project planning processes.

Dynamo-Developed specifically for Autodesk Revit, Autodesk Dynamo provides a visual programming platform that enables users to control this software by creating visual building blocks. These blocks represent various functionalities in Revit and also serve as an effective tool for developing constructions using graphical representation techniques without requiring lengthy programming languages. However, it is possible to integrate Python code within the Dynamo environment, further enhancing its versatility capabilities regarding coding tasks, which can be enhanced dynamically by custom online code packages. The custom online node packages are available from Dynamo's open-source package library, offering numerous functions and tools suitable for various levels of expertise.

2.4 Validation

The master thesis is concluded by validating the Gemalen Tool to determine whether a parametric modelling tool for water pumping stations is viable. In this phase, the main research question was answered. Validation was conducted based on the criteria defined in operationalising of the validation criteria. The performance of these criteria was evaluated for both the traditional design process and the design process using the Gemalen Tool. The results were then compared to determine whether the tool was a proven concept. The content of the validation phase overlaps with the operate and monitor phase of the DevOps methodology. The Gemalen Tool was also validated through a case study. The output model of the Gemalen Tool was compared with the output of a model created with the traditional design practice using the same design input.

Additionally, Chapter 7 evaluated the methodology used for the development of the tool, providing insight into the development process and potential areas of improvement. These improvements could lead to future advancements for the tool and its potential to become a proven concept or achieve even higher LOD. The objective of this phase was to validate if the parametric Gemalen Tool proved the concept of parametric modelling for water pumping stations, evaluate the applied methodologies, and identify future advancements of the tool.

3 THEORETICAL FRAMEWORK

The subsequent chapter expounds on the current state of scientific knowledge regarding parametric modelling, the applied methodologies, and the operationalization of validation criteria. The content of the theoretical framework is positioned in the existing research gap.

3.1 Parametric modelling

Recently, the demand for Building Information Modelling (BIM) in construction projects worldwide has increased attention regarding parametric modelling (Barazzetti, 2016). Parametric modelling is a computational design technique widely adopted by the architecture, engineering, and construction (AEC) industry (Aghimien, Aigbacboa, Oke, Thwala, & Moripe, 2020). In parametric design, a geometrical form is shaped by parameters and equations describing them instead of shaping a geometrical form by its structure and shape (Dzwierzynska & Prokopska, 2018). In other words, parametric modelling is a method of efficiently and adaptably designing geometry by using scripting, connecting decision variables and limitations to the geometry, setting up connections between components, and specifying the transformative behaviour of these components (Casini, 2022). In parametric design, two levels typically can be identified: the design knowledge level and the rule algorithm level. The design knowledge level relates to, i.e., the project environment and the user needs. The rule algorithm level includes the definition of the underlying design algorithm, which transforms parameters into possible design solutions (Tünger & Pektas, 2020) & (Kalkan, Okur, & Altunisik, 2018). Parametric designs are generated based on data and relations between different designs. Parametric modelling refers to virtual construction using well-defined components that understand their location, relationship with other components and composition (Barazzetti, 2016). The design algorithm connects the input and output logic of design components to the input of other components in a network composition (Kalkan, Okur, & Altunisik, 2018). The components in question are commonly referred to as objects or elements. Objects are a requirement for object-oriented modelling, which represents objects through parameters, rules and non-geometric information, and properties (Eastman, Teicholz, Sacks, & Liston, 2011).

The structural engineering and design environment is constantly evolving, leading to an increase in the use of parametric design as part of BIM (van Loenhout & Vissering, 2018). According to van Eck (2022), there are four motives for the parametrization of design, high degrees of iteration and reproducibility, the complexity of design, the need for optimization and flexibility during design. If one or more of these criteria are present, parametrization can be considered. The first reason to parameterize design is due to growing interest in pre-fabrication, modular building, and standardization in construction, which results in more iterative and reproduceable construction processes (Bonenberg, Wei, & Zhou, 2019) & (TNO, 2021). The second motive is the increasing complexity of construction projects, as well as larger project teams that involve multiple disciplines (Alaloul, Liew, Zawawi, & Mohammed, 2018). A parametric model captures multiple disciplines in one model. Thirdly, there is a growing demand for optimizations, focusing not only on monetary costs but also on materials, sustainability, and environmental impacts (Essam, Khodeir, & Fathy, 2023). Additionally, variant studies are becoming more common practices in the construction industry. Finally, a parametric model is suitable for achieving flexibility during design when multiple stakeholders are involved in the project and design alterations are likely (Dzwierzynska & Prokopska, 2018).

As mentioned earlier, parametric modelling is incorporated into the field of BIM, and therefore, the advantages of parametric modelling are interrelated to the advantages of BIM practices as a whole (Historic England, 2019). In other words, creating a comprehensive parametric model will lead to the benefits related to BIM. The main benefits of BIM can be divided into three main categories. The first is improved labour productivity, resulting in faster and more efficient processes. The second is better collaboration between stakeholders, including architects, engineers, contractors, and suppliers. The third benefit is the ability to more accurately estimate costs and other resources (Lou, Lu, & Xue, 2020), (Kivits & Furneaux, 2013) & (Love, Matthews, Simpson, Hill, & Olatunji, 2014). Creating BIM models using parametric modelling also provides specific advantages. Multidisciplinary experts collaboratively develop comprehensive parametric models, achieving interoperability and unambiguous interpretation of the objects by different disciplines (Wortmann & Tuncer, 2017). Furthermore, a parametric model captures technical formulas for creating complex geometries, constraints, and compositions. Parametrization of design serves as a fundamental facilitator for knowledge integration into a model (Cavieres, Gentry, & Al-Haddad, 2011)& (Okur, Okur, & Altunsik, 2018). Moreover, the dynamic nature of a parametric model allows for iteratively creating endless variations depending on input parameters. When altering the input parameters of the model, the dependent model changes accordingly, reducing the need for laborious manual design alterations (Vilgertshofer & Borrmann, 2017) & (Casini, 2022). Finally, design iterations are a powerful tool for optimization and can minimize the time needed to optimization of 3D models (Jabi, 2013). Lastly, the visual programming process in Autodesk's Dynamo is intuitive and easy to learn, without requiring sophisticated programming language knowledge (van Loenhout & Vissering, 2018).

Although parametric modelling offers benefits, there are challenges to its development and application. Creating a parametric model from scratch is a time-consuming and costly process and may not always yield sufficient results. Therefore, the application of parametric modelling should be justified and limited to complex and iterative work practices (Davis, 2013) & (van Loenhout & Vissering, 2018). Furthermore, some designs may be too complex or unique to parameterize, which can result in a time-consuming development process of the tool itself (Barazzetti, 2016). The parametrization of design also limits the flexibility, as design changes that cannot be captured by changing the input parameters require redevelopment, which is also time-consuming (Casini, 2022). Additionally, the functionality of a parametric model is limited to the intended scripted design algorithm, and structural input is still required. Another challenge is the current payment methods for construction and engineering work, which are based on providing a certain service that can be invoiced. Parametric modelling tools require other payment methods incorporating copyright infringements (van Loenhout & Vissering, 2018).

3.2 The Applied Technologies

In the following paragraphs, the techniques used during this research have been explained. The usability of these techniques for developing a parametric modelling tool will be evaluated for potential application in the to-be-developed framework.

3.2.1 OBJECT-ORIENTED MODELING (OOM)

One way to capture the non-graphic information to model elements is the application of Object -Oriented modelling (OOM). OOM is a modelling approach that views the system not as a set of functions but as a group of related, interacting objects. The OOM paradigm is commonly utilized in computer programming, known as Object-Oriented Programming (Marzouk, 2010). OOM allows users to create BIM model objects with customized behaviours and attributes that can control geometric representations and its attributes (Kim, Clayton, & Yan, 2013). Parametric objects are defined by the following characteristics: they possess both geometric information and data rules; they have non-redundant geometry without any inconsistencies; they are equipped with parametric rules that adjust connected geometries automatically in response to changes made to other objects; they can be defined at multiple levels of granularity; and they have the ability to link with or transfer object attributes to other programs (Eastman, Teicholz, Sacks, & Liston, 2011). Typically, an object includes its geometry, its descriptive information, and information about its connections. Parametric modelling has been integrated into the mainstream construction design through BIM, which is a comprehensive term that refers to the process of generating and maintaining digital information of buildings or other structures (Historic England, 2019). By adding metadata, such as material properties, weight, or performance, objects can be classified in greater detail and the content of the model is enriched (Pocobelli, Boehm, Bryan, Still, & Grau-Bové, 2018). This information can also be connected to the parametric algorithm, resulting in the properties of the objects adjusting automatically when changes are made to the input parameters of a model. Adding metadata to objects provides a comprehensive view of assets, which can be used to optimize decision-making and resource allocation in asset management. Additionally, the metadata can be the prerequisite for digital twins and Internet of Things (IoT) systems, which can help to improve real-time monitoring and predictive maintenance (Brous, Janssen, & Herder, 2020). Adding metadata to the model elements of the parametric model to be interpreted for other dimensions of BIM.

3.2.2 OBJECT TYPE LIBRARY (OTL)

As mentioned before, multiple disciplines are incorporated into a parametric model. Quick and easy transfer of information is crucial to collaborate in and during the development of a parametric model. Object Type Libraries (OTLs) are a proven method for structuring system data in a consistent and standardized manner using OOM (BIM-Connected, 2021). An OTL includes standardized object-type names, properties, and specifications that describe an object in terms of its data, geometry, and metadata. The systems ontology relates to the way objects are grouped (BIM-Connected, 2021). OTL helps to ensure that all stakeholders have a collective understanding of the objects and their underlying parameters. By defining the provisional information that should be included in an object to make it complete, an OTL facilitates collaboration among project teams and external firms and enables easy information transfer (Interlink, 2017)).

To develop an OTL, several steps must be followed, including setting a clear goal, utilizing standards, creating a structured architecture, and incorporating the required information (BIM-Connected, 2021). To develop an OTL for water pumping stations, the first step is to establish a clear goal. For the development of the preliminary design, the identified objects should have a minimum LOD 200. Secondly, standards such as NEN-2727-4 and Concepten Bibliotheek Nederland (CB-NL) leads to easier data transfer and interpretation (Interlink, 2017). Utilization of standards leads to clear communication with external parties, transparency and recognizability, and simplification of the data transfer. Thirdly, a clear structure or architecture should be developed to ensure multiple parties can easily understand the data. System architecture sometimes is available in certain standards; if not, the structure has to be thoughtfully developed. Finally, the necessary information should be described and incorporated into the OTL. The data included in the model will be minimal for the proof of concept, but the OTL should be designed to accommodate future advancements.

3.2.3 OBJECT BREAKDOWN STRUCTURE(OBS)

The development of an OBS is the process of breaking down an object into its constituent parts within a particular arrangement, going through enough levels to reveal the logical composition of the entire object collection within a particular setting (Bentley, 2023). For the creation of the OBS, the NEN 2767 method has been applied. The NEN 2767 is a standardized approach for objectively and consistently assessing the condition of built environment assets, with wide applicability across various disciplines, including hydraulic engineering. The NEN-2767 methodology consists of three levels of objects: Asset, Element, and Building or installation component. The Asset is a scoped entity of an overarching network, object portfolio complex, or acreage, which comprises a coherent whole of elements with one or more autonomous functions. The next level of aggregation is elements, which are identifiable parts of an Asset that are only distinguishable based on their desired function. The final level of aggregation is the Building or Installation component, which is a singular part of an element that can be identified based on its manner of construction or composition and consists of one or more components with related technical information and maintenance history (NEN, 2019). The OBSs developed for water pumping stations in this research, consists of three levels of aggregation: Asset, Element, and Building or installation component. The NEN 2767 methodology of the breakdown structure and the components are displayed in Figure 6.

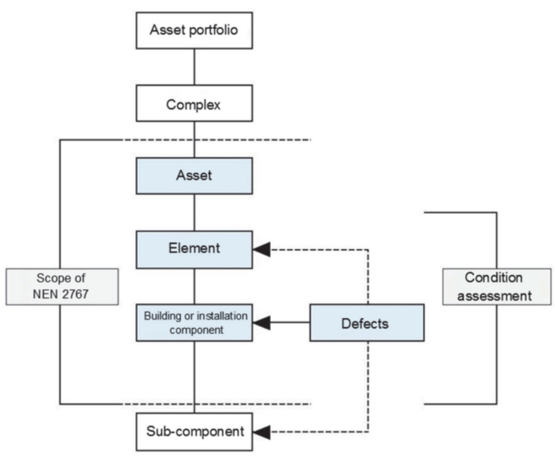


Figure 6: NEN 2767 decomposition methodology

3.2.3 DEVOPS

The parametric Gemalen Tool to be developed was developed using the DevOps methodology. According to Leite et al. (2019), DevOps is a collaborative and multidisciplinary approach to automate the continuous delivery of software updates while ensuring their correctness and reliability. In other words, DevOps encompasses a software-delivering method in which a team develops and guarantees the correctness and reliability of the tool. This approach involves a team working in small iterative cycles to develop, test and operate the software. The DevOps methodology is based on four main principles: Collaboration, Automation, Measurement, and Monitoring (Gokarna & Singh, 2021). The two main components of DevOps are Continuous Integration (CI) and Continuous Deployment (CD), depicted in Figure7.

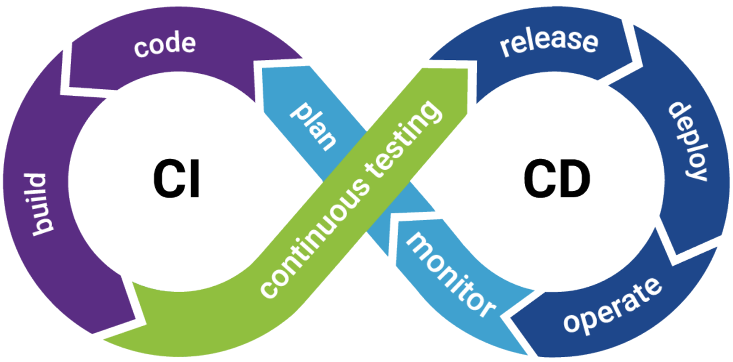


Figure 7: Continuous integration and Continuous deployment

Continuous Integration is one of the initial components of the DevOps methodology, which concentrates on software code development. Its objective is to enable developers to combine code changes in a shared codebase without conflicts. In this iterative process, the code is planned, coded, built and tested before it is merged into the primary code. Collaboration with experts processing the necessary knowledge for the planned code's objectives is vital during this process ((Leite, Rocha, Kon, Milojicic, & Meirelles, 2019). Continuous deployment automates the process of building, testing, configuring, and deploying code into functioning processes (Mohammed, 2020). Once a code has been developed and tested in the Continuous Integration cycle, it is added to the main program code. In this phase, the code's functionality is tested and operated against the main code, and the results are monitored. If necessary, new plans for the code are added. Successful completion of this phase initiates the next iterative cycle (Gokarna & Singh, 2021).

For conceptualization of the methodology for the development of the Gemalen Tool, the components of the DevOps methodology are assessed in relation to the required resources and software. In Figure 4, the conceptual framework consists of the components: Plan, Code, Build, Test, Release, Deploy, Operate and Monitor. The tools and knowledge resources are included in the model.

3.3 Operationalization of critical success factors

To develop a proof of concept of a parametric modelling tool, validation is essential. Validation involves verifying if it meets predetermined criteria for quality, it evaluates whether a product, service or system meets theoretical and empirical standards (Dutta & Dhir, 2021). The predetermined criteria for validation of the parametric modelling tool are increased design efficiency, functionality, and usability. The pre-selection of criteria for the parametric modelling tool to be considered a proven concept is based on meetings with water pumping station experts of TAUW and WF. These criteria align with three of the eight quality characteristics identified in ISO 25010 (ISO 25000, 2023). To measure the criteria, they need to be operationalized. Operationalisation involves specifying the variables, measures, and interpretation methods (DeCarlo, 2018). The characteristics of the ISO 25010 will be used for the operationalisation, since they provide consistent terminology for specifying, measuring, and evaluating system and software products. The ISO 25010 was chosen over other methods because the evaluation can be expanded by evaluating the other characteristics of software quality incorporated in the ISO 25010 after finalizing the tool.

This chapter will operationalise the pre-defined criteria to evaluate the tool's effectiveness. The operationalised criteria were evaluated during phases two and four of the research. The criteria are evaluated for traditional design practice in the second phase of the research, and for design practice using a parametric modelling tool in the fourth phase. A closed-ended survey is completed during expert meetings in consultation with the experts. The evaluation survey gathers quantitative and qualitative data, depending on the criteria and sub-characteristics being measured. Specific questions are determined for each criterion and identify the corresponding data type. All data was analysed in Excel, and visualizations of the results were created. Since the responses will result in ordinal data, the modus can be calculated as a central tendency. The Validation process was conducted in two groups during the expert meetings: potential users of the tool, represented by experts from WF and the tool owners, represented by experts of TAUW.

3.3.1 EFFICIENCY

The first characteristic that will be assessed is the criterion of efficiency. The Gemalen Tool is evaluated based on its ability to improve efficiency, by reducing the time spent on design. The traditional design process for water pumping stations is time-consuming, and there is a shortage of qualified engineers and designers, making it imperative to reduce the design effort. According to ISO (2022), efficiency is defined as performance relative to the time behaviour, resource utilization and capacity, used under stated conditions. The first sub-characteristic of efficiency is the time-behaviour. Time behaviour refers to the extent to which a product or system's response time, processing time, and throughput rates meet the requirements while performing its functions. The second sub-characteristic is resource utilization. Resource utilization refers to the extent to which a product or system uses the appropriate types and amounts of resources during its function to meet the requirements. The final sub-characteristic of efficiency is capacity. Capacity refers to the extent to which a product or system parameter's maximum limits meet requirements. The following questions have been operationalized to evaluate the sub-characteristics for assessing the overall improved efficiency when using parametric modelling, of which all the answers can be compared for the traditional and parametric modelling approach for compiling a preliminary design:

Sub - Characteristic	Questions	Datatype	Output
Time Behaviour	*Traditional: How many design hours(approximately) are required for the development of a preliminary design using Traditional Design Practices?*	Quantitative	Time in design hours
	Parametric: How many design hours(approximately) are required for the development of a preliminary design using a parametric modelling tool?	Quantitative	Time in design hours
Resource Utilization	*Traditional: The number of resources(effort) is utilized effectively during traditional design practices?*	Qualitative	Level of agreement
	Parametric: The number of resources(effort) is utilized effectively when using (not developing) the parametric modelling tool?	Qualitative	Level of agreement
Capacity	*Parametric: The maximal limits of the system input parameters meet the requirements?*	Qualitative	Level of agreement

3.3.2 FUNCTIONAL SUITABILITY

In the validation process of the parametric Gemalen Tool, the second criterion assessed is the functional suitability of the product or services. The criterion refers to the extent to which a system or product meets stated and implied needs when used under specific conditions and can be decomposed into three sub-characteristics: functional completeness, functional correctness, and functional appropriateness (ISO 25000, 2023). Functional completeness evaluates the extent to which a set of functions covers all specified tasks and user objectives of the system, including the design algorithm for compiling a complete design of a water pumping station. Functional correctness evaluates the extent to which a product or system provides correct results with the required degree of precision. The achieved precision of traditional design practice is compared to the parametric model produced by the Gemalen Tool during validation of the latter based on achieving the desired LOD. Functional appropriateness evaluates the extent to which the functions facilitate the accomplishment of specified tasks and objectives, including reaching the objective of a preliminary design. For validation of the functional suitability, comparing traditional and parametric modelling practices is not applicable as the traditional design is always assumed to achieve the desired functionality. Thus, the evaluation of functional suitability focussed solely on evaluating the development of a preliminary design of a water pumping station using the parametric modelling tool. The sub-characteristics for evaluating the overall improved functional suitability when using parametric modelling have been operationalized through the following questions:

Sub-Characteristic	Questions	Datatype	Output
Functional Completeness	*The preliminary design developed with the parametric modelling tool, reaches the intended elements of preliminary design?*	Qualitative	Level of agreement
Functional Correctness	*The Parametric modelling tool reaches a detail level required for a preliminary design?*	Qualitative	Level of agreement
Functional Appropriatenes s	*The parametric model is an appropriate method for the development of a preliminary design?*	Qualitative	Level of agreement

3.3.3 USABILITY

The final predetermined criterion is the usability of the parametric model compared to the traditional process. Usability is defined by ISO (2022) as the extent to which a product or system can be effectively, efficiently, and satisfactory used by specified users to achieve specified goals. According to ISO 25000 (2023), usability can be broken down into appropriateness & recognizability, learnability, operability, user error protection, user interface aesthetics, and accessibility. Appropriateness & Recognizability refers to the extent to which users can recognize a product or system as appropriate for satisfying their needs. Learnability refers to the level at which users are able to learn the product effectively and efficiently, with satisfaction and without risks in a specified context. Operability can be defined as the extent to which a product or system has attributes that make it easy to operate and manage. User error prevention refers to the degree to which a system or products prevent the user from making errors. The user interface aesthetics relate to the extent of the aesthetically pleasing interface allowing the user to interact satisfactory. Finally, accessibility refers to the degree to which a system or product can be used by people with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use. Similar to the functional suitability criterion, the traditional design process of a preliminary design will not be evaluated and compared for suitability since it focuses on the application of specific software. Therefore, the sub-characteristics for assessing the overall usability when using parametric modelling have been operationalized through the following questions:

Sub-Characteristic	Questions	Datatype	Output
Appropriateness & Recognizability	*It is possible to recognize if the parametric model meets appropriate results?*	Qualitative	Level of agreement
Learnability	*Specified users are able to learn working with the system in an effective and efficient way?*	Qualitative	Level of agreement
Operability	*Specified users are able to operate the tool?*	Qualitative	Level of agreement
User Error Protection	*The system prevents the user making mistakes or misinterpret the application?*	Qualitative	Level of agreement
User Interface Aesthetics	*The user interface of the parametric tool is aesthetically pleasing?*	Qualitative	Level of agreement
Accessibility	*The application is operatable by any user with only little knowledge of water pumping stations?*	Qualitative	Level of agreement

3.4 Sub-Conclusion Theoretical Framework

As described in the theoretical framework, the use of parametric modelling tools can contribute to the issue of replacing pumping stations in the Netherlands. Traditional design practices are time-consuming and require a significant amount of labour from scarce civil designers and engineers. Parametric modelling tools can be applied when the design is iterative, has an appropriate level of complexity, requires optimization, and demands flexibility. The design of water pumping stations within WF's management acreage is considered iterative due to the fact that over 300 stations within the specified range need to be replaced in the upcoming decade. The design is also sufficiently complex and not overly unique. Furthermore, there is a lesser demand for optimizing the design; however, this could be explored further using parametric modelling. Lastly, there is a high demand for flexibility during the design process of water pumping stations due to the frequent need for generating multiple alternatives.

The utilization of the OOM methods OTL and OBS aims to provide clarity regarding the components comprising a pumping station. This approach was employed to establish a unified understanding of the components within a water pumping station. The information gathered from consultations with experts from TAUW and WF, using a scope overarching general OTL, facilitated the development of an OTL and OBS specific to the scoped range appliable for water pumping stations in the acreage of WF.

In order to verify whether or not a pumping station meets predefined objectives, it must be subjected to validation criteria encompassing efficiency, functionality, and usability. There is also recognition that improvements in the design process are necessary for enhancing efficiency while ensuring that the parametric modelling tool for water pumping stations attains satisfactory levels in terms of functionality and usability.

Once the effectiveness of this methodology for parameterizing a water pumping station has been demonstrated using the applied development methods, it becomes feasible to utilize the same methodologies for the development of new products. Moreover, the potential applications warrant further investigation.

4 DECOMPOSITION OF WATER PUMPING STATION

As outlined in the methodology, this chapter is dedicated to the decomposition of a water pumping station within the defined scope. Initially, an extensive examination of practical, technical, and academic documentation and literature was conducted to identify the components of a water pumping station that had yet to be developed specifically for water pumping stations within the given range. To develop tailored OTLs and OBSs specific to water pumping stations within the defined scope, discussions were held with experts from TAUW and WF, utilising the general components of existing OTLs and OBSs for water pump stations as a starting point. Subsequently, each component was analysed in terms of its geometry and parameterisation factors that determine its size and shape. In order to achieve parametric design capabilities for a water pumping station, essential design parameters, in addition to the current design input parameters, were deemed indispensable, building upon traditional design practices.

4.1 Development of OTL & OBS

4.1.1 OTL

The initial phase of the decomposition process involved the development of a customized OTL specifically tailored for the modelling of water pumping stations within the defined range. A suitable set of elements was carefully selected to represent a water pumping station with a capacity ranging from 5 to 15 m3 per minute while ensuring a minimum LOD of 200. The creation of the OTL was carried out in collaboration with experts from TAUW and WF, resulting in the OTL presented in Table 3. The OTL includes an identification number that corresponds to the elements in the OBS, accompanied by their respective definitions and sources to create a mutual understanding of the elements of a water pumping station. For a visual representation of the objects and a more comprehensive description of the elements, please refer to Appendix 1.2.

Table 3: OTL

ID	Object	Definition	Source
0.0	Gemaal (English: Water Pumping Station)	In principle, a pumping station serves to bring water from a low level to an elevated level, the necessity of which may lie in water surplus on the low side(discharge) or in water demand in the area on the high side(supply).	(Aquo, 2023)
1.0	**Instroomconstructie (English: Inlet Construction)**	**Construction through which a stream of water (from a water course, lake, basin, etc. flows in.**	**(Waternet, 2023)**
1.1	Beschoeiing (English: Revetment)	Revetment is a bank protection consisting of a perpendicular wall that prevents the bank from eroding.	(de Vree, 2023)
1.2	Bodembescherming (English: Bottom Protection)	Covering the soil, for example with rubble or stone, which is aimed at preserving the quality of the bottom of the adjacent waterbodies.	(Waternet, 2023)
1.3	Fundering (English: Foundation)	Construction, located underneath the ground level, to distribute forces over the underlying ground or transfer them to a deeper load-bearing layer.	(Waternet, 2023)

1.4	Instroombak (English: Inlet Reservoir)	Structural part belonging to an inlet construction to prevent soil leaching.	(Waternet, 2023)
1.5	Instroomdek (English: Inlet Deck)	Construction part consisting of a deck over the inflow construction, covering the pump installation.	(Waternet, 2023)
1.6	Krooshek (English: Trash Rack)	Structure for retaining dirt to prevent damage to installations and blockages	(Waternet, 2023)
1.7	Kroosleuning (English: Trash Rail)	Construction part that prevents the employee from falling into the water cleaning the trash rack. (Only applicable at fixed Krooshek.	(Waternet, 2023)
1.8	Kwelscherm (English: Cut-Off Wall)	An impermeable, vertical, construction for extending the seepage line.	(Aquo, 2023)
1.9	Leuningwerk (English: Railing)	Construction mounted on a wall that provides support and protection against falls when there is a difference in height.	NEN 2767-4
1.10	Luik (English: Hatch)	Horizontal removable plate with hinges and handles to close off a room.	NEN 2767-4
1.11	Niveaumeetbuis (English: Level Measuring Tube)	A tube for managing and monitoring level measurements in the field as part of a telemetry system.	CROW
1.12	Slibschot (English: Sludge Barrier)	Plate with sludge-stopping function that is fitted to the front of the inlet construction	Waternet/Expert meetings
1.13	Sponning (English: Groove)	Groove in a construction in which a door, window, or bulkhead(beam) can be placed.	(Waternet, 2023)
1.14	Vleugelwand (English: Retaining Wall)	Retaining wall, which is installed on front walls and abutments to support the embarkment and is usually skewed on it.	(Waterschap Hunze en Aa's, 2023)
2.0	**Werktuigbouwkundige Installaties (English: Mechanical Engineering Parts)**	**Installations that fall under the Mechanical Engineering Parts.**	**Expert meetings**
2.1	Krooshekreiniger (English: Trash Rack Cleaner)	Automated trash fence, which is a structure for retaining dirt to prevent damage to installations and blockages.	(Waternet, 2023)
2.2	Ontluchting (English: Vent)	Installation that allows air to escape form a pipe or pump system manually or automatically.	(Waternet, 2023)
2.3	Persleiding (English: Presure Pipe)	Pipe through which medium is pumped under pressure.	(Aquo, 2023)
2.4	Pompinstalatie (English: Pump Installation)	Installation that can move a liquid or gas using a pump.	NEN 2767-4
2.5	Terugslagklep (English: Non-Return Valve)	Valve that is used to allow water, liquid, granules, powder, or gas to pass in only one direction and closes when the flow is reversed.	NEN 2767-4
3.0	**Uitstroomconstructie (English: Outlet Construction)**	**Construction through which water flows out.**	**(Waternet, 2023)**

3.1	Beschoeiing (English: Revetment)	Revetment is a bank protection consisting of a perpendicular wall that prevents the bank from eroding.	(Waterschap Hunze en Aa's, 2022)
3.2	Bodembescherming (English: Bottom protection)	Covering the soil, for example with rubble or stone, which is aimed at preserving the quality of the bottom of the adjacent waterbodies.	(Waternet, 2023)
3.3	Fundering (English: Foundation)	Construction, located underneath the ground level, to distribute forces over the underlying ground or transfer them to a deeper load-bearing layer.	(Waternet, 2023)
3.4	Kwelscherm (English: Cut-Off Wall)	An impermeable, vertical, construction for extending the seepage line.	(Aquo, 2023)
3.5	Leuningwerk (English: Railing)	Construction mounted on a wall that provides support and protection against falls when there is a difference in height.	NEN 2767-4
3.6	Sponning (English: Groove)	Groove in a construction in which a door, window, or bulkhead(beam) can be placed.	(Waternet, 2023)
3.7	Uitstroombak (English: Outlet Reservoir)	Structural part belonging to an inlet construction to prevent soil leaching.	(Waternet, 2023)
3.8	Uitstroomdek (English: Outlet Deck)	Construction part consisting of a deck over the outlet construction, covering the pump installation.	(Waternet, 2023)
3.9	Vleugelwand (English: Retaining Wall)	Retaining wall, which is installed on front walls and abutments to support the embarkment and is usually skewed on it.	(Waterschap Hunze en Aa's, 2023)
4.0	**Terrein (English: Terrain)**	**Visibly demarcated piece of land characterized by a type of land use.**	**NEN 2767-4**
4.1	Hekwerk (English: Fencing)	Construction consisting of, for example, poles, battens, or bars for separating different areas of the site.	NEN 2767-4
4.2	Poort (English: Gate)	Gate is a closable opening withing a partition.	(Waternet, 2023)
4.3	Terreinvelichting (English: Lighting)	Element that provides lighting for the complex.	(Waternet, 2023)
4.4	Verharding (English: Pavement)	Construction consisting of one or more layers, to keep the terrain easily accessible for people and vehicles.	(Waternet, 2023)
5.0	**Elektronische installatie (English: Electro Instalations)**	**The whole of all associated electrical equipment, and connections that are located on the site.**	**NEN 2767-4**
5.1	Kast (English: Box)	Lockable housing that serves to store and/or protect something.	NEN 2767-4

4.1.2 OBS

In collaboration with water pumping station experts from TAUW and WF, the OBS depicted in Figure 8 has been created, building upon the OTL presented in the preceding section. The OBS follows the NEN-2767 decomposition methodology, as elucidated in Section 3.2.3. It comprises three levels of aggregation: Asset, Element, and Building or Installation Components. At the highest level, an asset represents a comprehensive network structure that integrates multiple elements to fulfil a primary function. Elements, conversely, are individual components of a structure or network that collectively contribute to an Asset. At the lowest level of aggregation, building or installation elements correspond to specific components with their own dedicated installation or construction methods.

The development process of the OBS adhered to the aforementioned methodological framework, as illustrated in Figure 6. The translations of the OBS objectives can be found in the OTL associated with corresponding ID numbers. In addition, visualizations have been added to show the allocation of the objects within a water pumping station. Enlarged displays of those figures and the OBS can be found in Appendix 1.1 & 1.2.

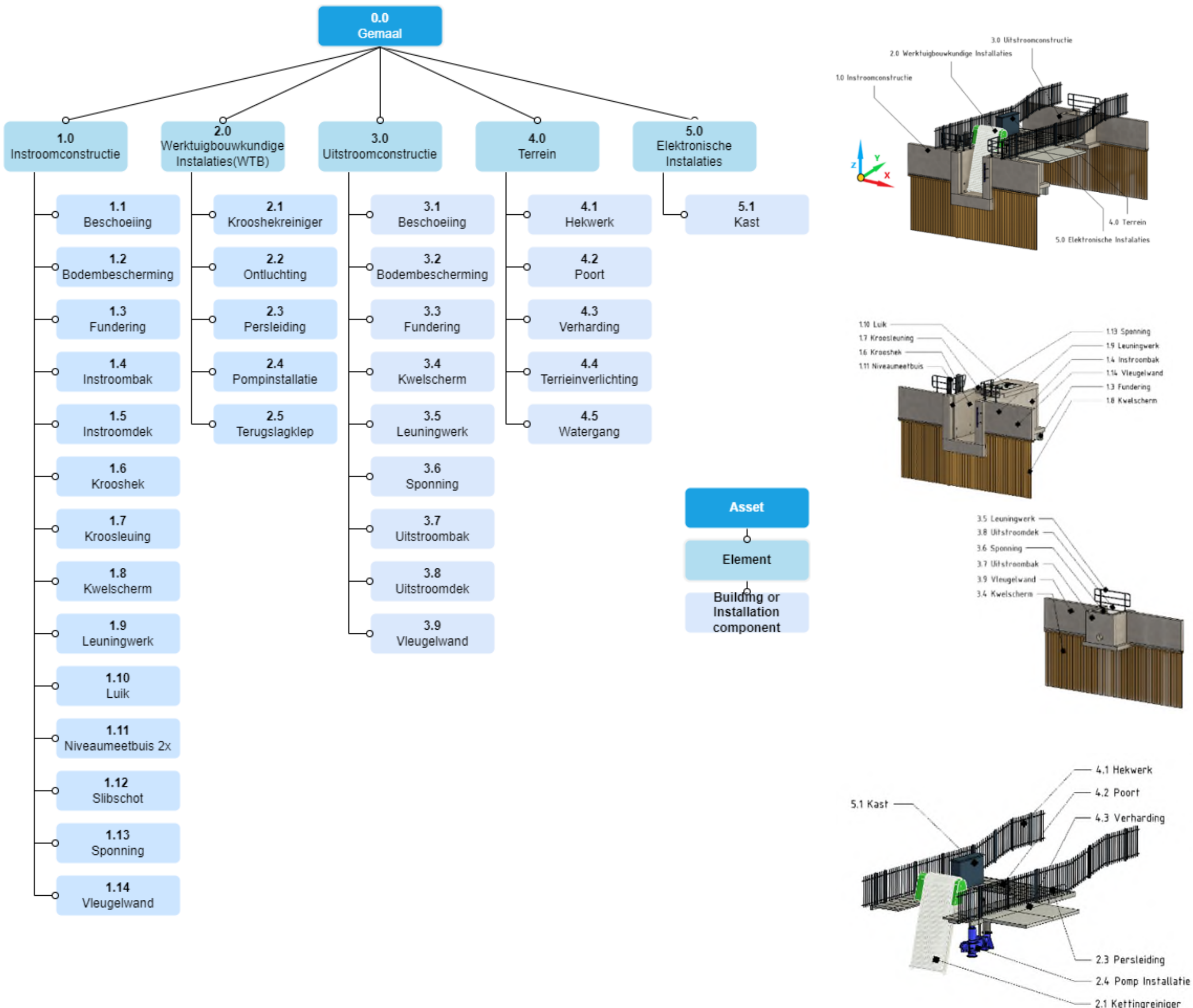


Figure 8: OBS & reference images

4.2 Fundamental design logic

Once the objects of a water pumping station had been identified, the next step was to determine the design grammar underlying the design. As depicted in the methodology, the basic input for using the Gemalen Tool is based on the traditional design practices at WF as the tool needs to replace the traditional process. In the traditional process they make use of an Excel spreadsheet filled in by an expert in water technology. The Excel spreadsheet is considered as the Input variables of the Gemalen Tool. In Figure 9, the traditional design spreadsheet is displayed.

For the tool to be advanced further, the tool had to be built in a logically in that the Excel spreadsheet could be replaced by interactive map data and underlying design algorithms based on databases. Therefore, the underlying design logic had to be based on the creation of the design of a water pumping station in the traditional manner. In doing so, the traditional design steps, as outlined in "Bouwprocess: Beschrijving van het bouwproces voor opervlaktewater gemalen," is included into the logic of the tool (TAUW, 2011). According to this document, the design process of water pumping stations consists of the following main steps: 1) Hydraulic design of the wet path, 2) Mechanical design, and 3) determination of civil structures adapted to the dimensions of the wet path and mechanical equipment. However, before following the traditional steps of design, the location of the pumping station must be determined. In the traditional design process, the location of the water pumping station is always given before the design process begins. The location is based on the location of the Instroom- and Uitstroomconstructie. The Instroom- and Uitstroomconstructie determine the location of the entire pumping station and its components. Together these two structures determine the width of the pumping station, the layout of the water pumping station, and the underlying distance between the two structures. After determining the location, the water flow path through the structure has to be determined, also known as the "wet path." To determine these values, water levels and heights of the structures in the landscape need to be provided. After that, the mechanical components are selected, and their dimensions may be adjusted if necessary. The mechanical components in a water pump station typically include a trash rack "Dutch: Krooshek" and pump installation. Finally, other civil design considerations are incorporated into the overall design, such as wall- and floor thicknesses and space required for accommodating equipment. In Figure 9, the Excel spreadsheet is displayed, with the parameters identified for the unique design steps.

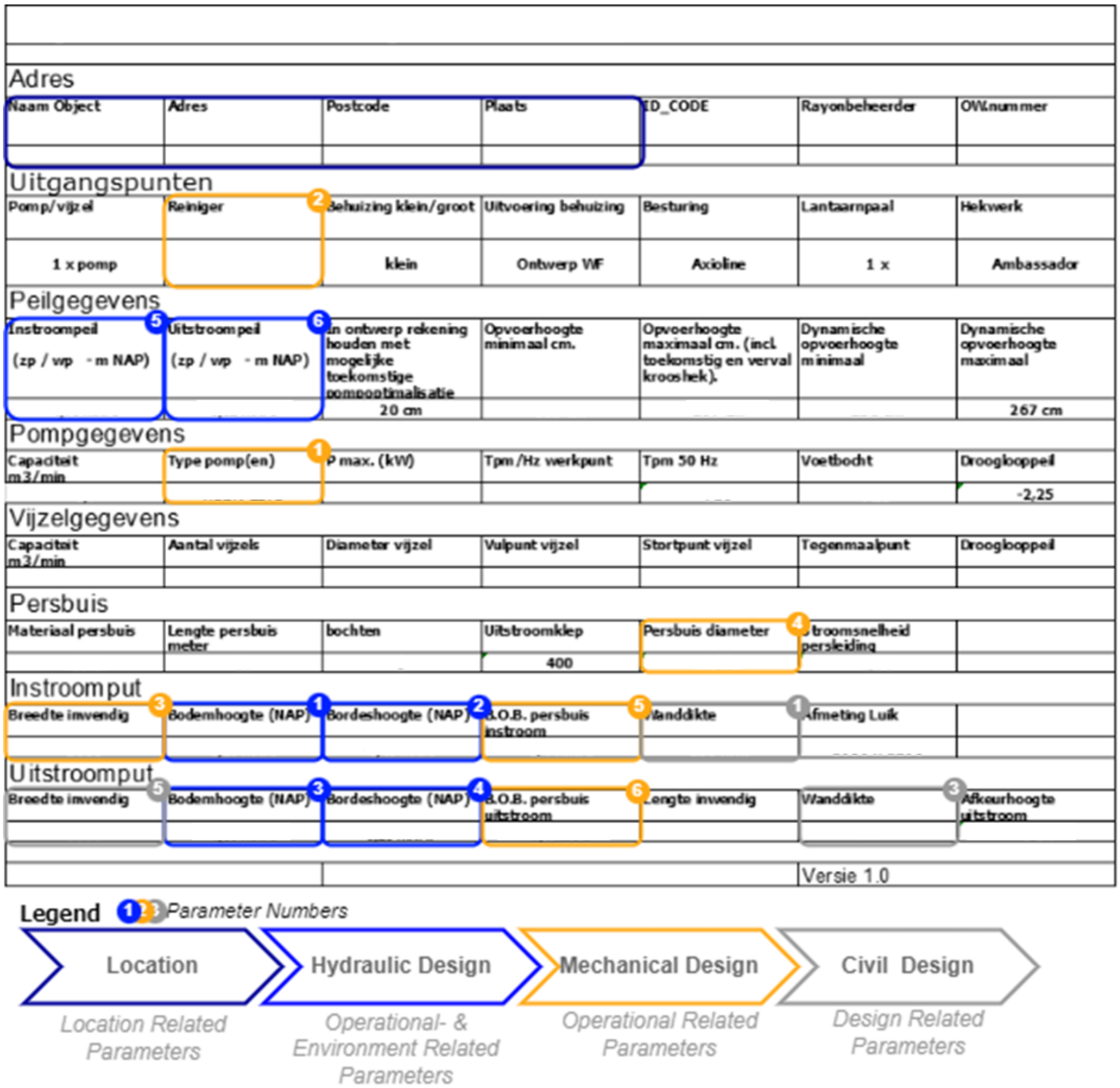


Figure 9: Excel Spreadsheet of WF & Design Steps

Based on the Excel spreadsheet displayed above, and the steps of traditional design practices described in Bouwprocess: Beschrijving van het bouwproces voor oppervlaktewater gemalen," the design logic sequence displayed at the bottom of Figure 9 can be distinguished. The first step of the design sequence is the location that had to be determined, which refers to the coordinates of the endpoints of the Instroom- and Uitstroomconstructie. The endpoints should be determined by the edges of the retaining walls on either side of the watercourse for both the Instroom- and Uitstroomconstructie, or if not possible, then the desired edges should be determined. Secondly, the hydraulic design needs to be defined by determining the lowest water levels on both sides of the water pumping station and the heights of both the bottom and top floors. The operational and environment related parameters define how the structure fits into its surroundings and guide water flow through it. Thirdly, the mechanical parameters need to be included. These parameters determine the dimensions of the structure based on the space required for accommodating the mechanical elements. The mechanical elements included, among others, the Krooshekreiniger and Pump installation. Lastly, inputting the remaining parameters that affect the design is necessary; these are referred to as design-related parameters. The Parameter Numbers added in Figure 9 represent reference numbers that will be discussed in Section 4.3.1.

4.3 Identification of design grammar and parameters

The design grammar could be identified after analysing the input Excel Spreadsheet and the fundamental design logic. In order to achieve the desired LOD of the Gemalen Tool, it was necessary to minimise the number of parameters that needed to be filled in. Minimising these parameters would have a positive impact on the usability of the final product. The identified parameters can be distinguished in four parameter categories. The first parameter category consists of the parameters relevant to the location of the water pumping stations. These parameters traditionally are considered given and included as part of the design input. In addition, some parameters on the excel spreadsheet define the basics of design, which are provided on the Excel spreadsheet. Secondly, there are background parameters that have an influence on the design but are not included on the Excel spreadsheet. Thirdly, there are parameters that originate from a database which depends on the design's choice of certain mechanical components. Lastly, calculated parameters need to be determined, which depend on the parameters in the aforementioned categories. This section will further examine the parameter types and provide visualisations to clarify the diverse types of parameters and their location. The parameter names will be built upon the structure as displayed in Figure 10

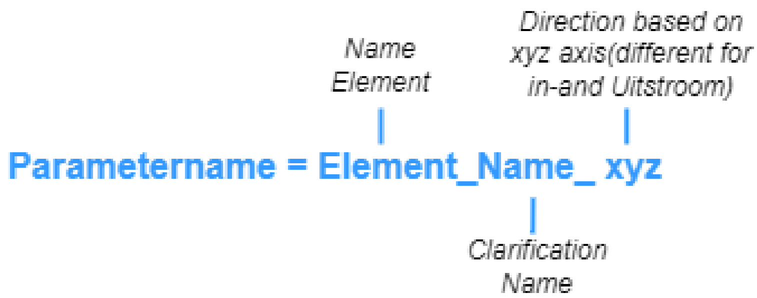


Figure 10: Parameter name structure

4.3.1 PARAMETERS FROM EXCEL SPREADSHEET

The first parameters that needed to be incorporated in the Gemalen Tool should correspond to the parameters outlined in the Excel Spreadsheet. A brief description of each parameter's effect can be found in the description column. Additionally, this column refers to the corresponding Parameter Numbers in Figure 9. The table underneath shows all the parameters that are given prior to designing a water pumping station. The table includes both the location and parameters as the parameters that are on the Excel Spreadsheet of WF.

Table 4: Excel spreadsheet parameters

Parameter Name	Units	Discription
Instroom_Coordinate Begin Midline	-	RD-NEW Coordinate located at the midline at front of the instroomconstruction
Instroom_Coordinate End Midline	-	RD-NEW Coordinate located at the end of the midline at the back site of the wall of the instroomconstructie
Uitstroom_Coordinate Begin Midline	-	RD-NEW Coordinate located at the midline at front of the instroomconstruction
Uitstroom_Coordinate End Midline	-	RD-NEW Coordinate located at the end of the midline at the back site of the wall of the instroomconstructie
Instroom_Bordeshoogte_z	mmNAP	Hydraulical Parameter that is on the Excel spreadsheet nr.1, Determines the height of upperside top floor Instroomconstructie
Instroom_Vloerhoogte_z	mmNAP	Hydraulical Parameter that is on the Excel spreadsheet nr.2, Determines the height of upperside bottom floor instroomconstructie
Instroom_Binnenbreedte_x	mm	Operational Parameter that is on the Excel spredsheet nr. 3, Determines the whith in-between the walls of the Instroomconstructie
Instroom_Wanddikte	mm	Civil Design Parameter that is on the Excel spreadsheet nr. 1, Determines all the wall thicnesses of the Instroomconstructie
Instroom_Waterpeil	mmNAP	Hydraulical Parameter that is on the Excel spreadsheet nr.5, Determines height of end/begin Cut-Off & Retainingwall
Instroom_BOB	mmNAP	Mechanical Parameter that is on the Excel spreadsheet nr. 5, Determines height of underside of the presure pipe at the end of the Instroomconstructie
Uitstroom_Bordeshoogte_z	mmNAP	Hydraulical Parameter that is on the Excel spreadsheet nr.4, Determines the height of upperside top floor Uitstroomconstructie
Uitstroom_Vloerhoogte_z	mmNAP	Hydraulical Parameter that is on the Excel spreadsheet nr.3, Determines the height of upperside bottom floor Uitstroomconstructie
Uitstroom_Binnenbreedte_x	mm	Civil Design parameter that is on the Excel spredsheet nr. 5, Determines the whith in-between the walls of the Uitstroomconstructie
Uitstroom_Wanddikte	mm	Civil Design Parameter that is on the Excel spreadsheet nr. 3, Determines all the wall thicnesses of the Uitstroomconstructie
Uitstroom_Waterpeil	mmNAP	Hydraulical Parameter that is on the Excel spreadsheet nr.6, Determines height of end/begin Cut-Off & Retainingwall
Uitstroom_BOB	mmNAP	Mechanical Parameter that is on the Excel spreadsheet nr. 6, Determines height of underside of the presure pipe at the end of the Uitstroomconstructie
Type_Pump	-	Mechanical Parameter that is on the Excel spreadsheet nr 1, Determines type of pump
Type_Krooshek	-	Mechanixal Parameter that is on the Excel spreadsheet nr 2, Determines type of krooshek
Diameter_Persleiding	mm	Mechanical Parameter that is on the Excel spreadsheet nr 4, Determines Diameter of Persleiding

4.3.2 DESIGN PARAMETERS

The second set of parameters refers to the design parameters. These parameters are not initially included in the Excel spreadsheet but must be added to the parameter list because their values determine the overall design. The specific values for these design parameters were determined through a comprehensive study conducted on three different models of water pumping stations that fell within the scope of this research project. During this study, analysis was performed to identify any standardizations or commonalities in terms of design among all three models. This process involved searching for geometry that remained consistent across all three models. Through expert meetings held at WF, discussions took place regarding the identification and determination of standardized values for these particular design parameters. Although fixed in nature, it is important for these parameters to sill remain adjustable within the Gemalen Tool to allow flexibility and facilitate potential variations if necessary. In Figures 11(Instroomconstructie) and 12(Uitstroomconstructie), a reference image is provided for the locations of the design parameters in the layout.

Table 5: Design parameters

Parameter Name	Units	Discription	Ref. Figure
Instroom_sponning_y	mm	Determines dimensions of the sponning in the y_direction of instroom	1.E
Instroom_sponning_x	mm	Determines dimensions of the sponning in the x_direction of instroom	1.F
Instroom_dikteneus_y	mm	Determines dimensions of the dikteneus in the y_direction of instroom	1.B
Instroom_breedteneus_x	mm	Determines dimensions of the breedteneus in the x_direction of instroom	1.A
Instroom_voorkantnaarsponning_y	mm	Determines dimensions of the front side of Instroomconstructie to the sponning	1.C
Instroom_sponningnaarkrooshek_y	mm	Determines distance of the sponning to krooshek in the y_direction	1.D
Instroom_kroosheknaarluik_y	mm	Determines distance of the krooshek to sponning in the y_direction	1.L
Instroom_fundatielengteliggers_x	mm	Determines dimensions of the fundatielengteliggers in the x_direction	1.I
Instroom_fundatiebalkvoorkant_y	mm	Determines dimensions of the fundatiebalkvoorkant in the y_direction	1.J
Instroom_vloerdikte_z	mm	Thickness of floor for upper and lower floor of Instroomconstructie	
Instroom_hoogtefundat	mm	Determines dimensions of the hoogtefundatie in the	-
peildiepte_kwelscherm	mm	Determines dimensions of the kwelscherm pe the kwelscherm_direction	-
overlengte_vloertbvgrondwerkin_y	mm	Determines dimensions of the floorfor earthworks at the back of the Instroom y_direction	1.M
afstandfundatietotrand_x	mm	Determines dimensions of the foundationbeams in the lenght direction to the sides of the floor at the	1.K
Uitstroom_achterkantneustotachterkant_y	mm	Determines dimensions of the hinterside of the neus to the the y_direction	2.A
Uitstroom_breedteneus_x	mm	Determines dimensions of the breedteneus uitstroom in the x_direction	2.B
Uitstroom_dikteneus_x	mm	Determines dimensions of the dikteneus uitrooom in the x_direction	2.C
Uitstroom_vloerdikte_z	mm	Thickness of floor for upper and lower floor of Uitstroomconstructie	-

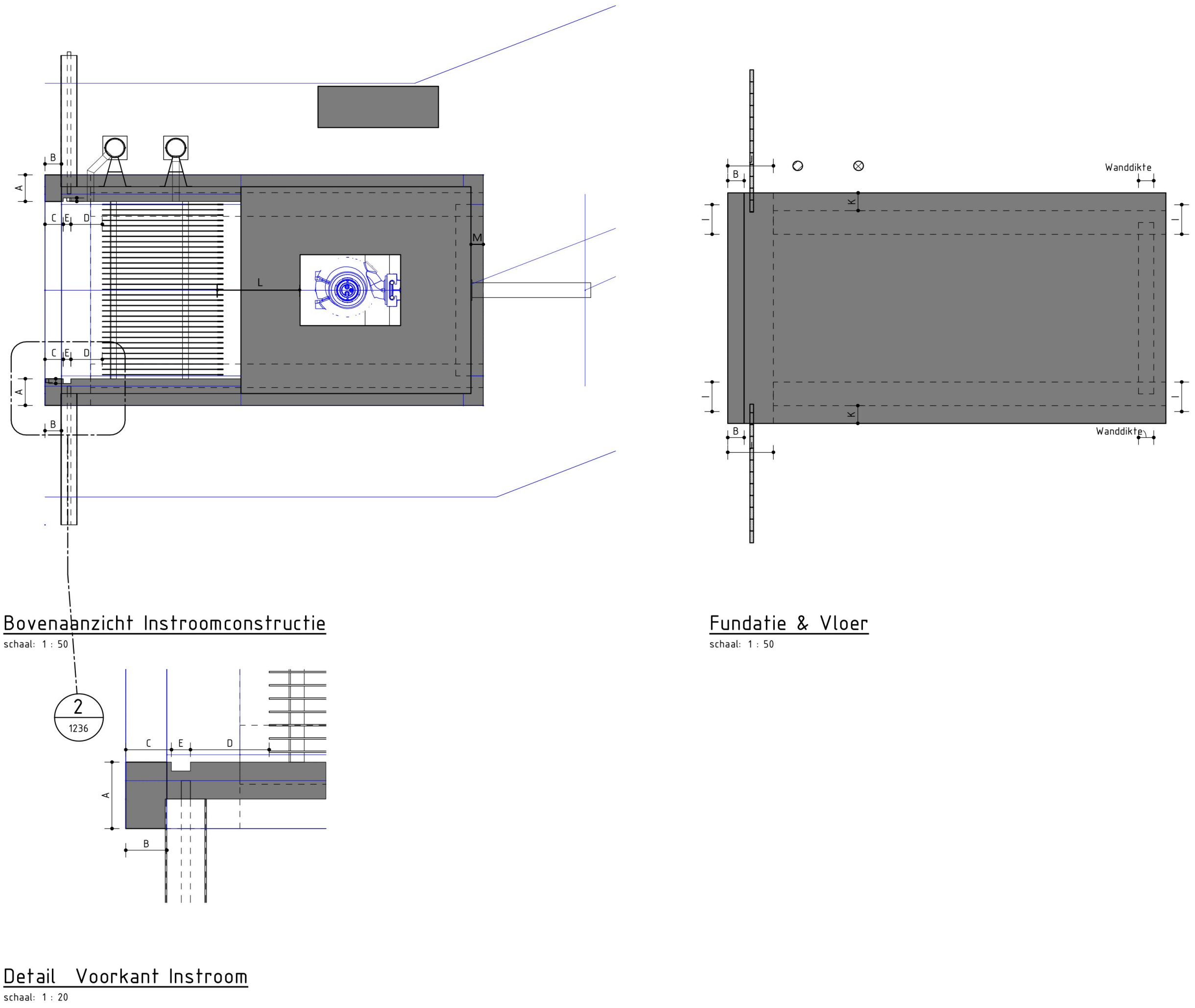


Figure 11: Reference Image 1

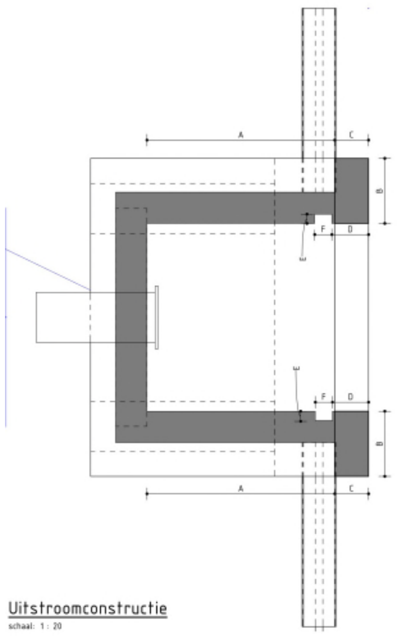


Figure 12: Reference Image 2

4.3.3 PARAMETERS FROM DATABASES

The following set of parameters that needed to be incorporated are those derived from decisions regarding mechanical equipment. The principle of database inclusion has been implemented in order to allow for future expansion if there is a requirement to incorporate additional types of mechanical equipment at a later stage. The initial database contains parameters that are influenced by the choice of pump type. These parameters resemble a list provided by the pump supplier Hidrostal. For now only four parameters from the database are utilized, namely: C, Z, Luik x and Luik y. Other parameters could be utilised if the model were to be expanded and automated regarding pump selection. As for the database pertaining to parameters dependent on the choice of Krooshek, there are two practical options: a fixed trash rack (Vast Krooshek) or one with its own automatic cleaner (Kettingreiniger). The inclination angle determines the clearance beneath the Krooshek in the Y-direction that has to be incorporated into the concrete construction design. The angles and the added distance that have to be considered for the two types of Krooshek can be found in Table 7. Reference images with the allocation of the pump parameters and Krooshek parameters can be found in Figures 13(pump) and 14 & 15(krooshek).

Table 6: Pump type parameter database

Parameter Name	H12K-LLT1	I16K	F10K
A	300	400	250
B	275	360	450
C(in inch)	2,5	3	2,5
D	110	120	105
DC	440	625	450
DD	735	1020	552
E	110	110	110
F	750	850	800
G	490	560	470
GC	550	610	520
H	500	640	500
HC	630	800	630
HH max	1970	2500	1810
I	23	23	23
K	350	360	350
L	600	650	570
M	1450	1900	1200
N	1200	1500	100
O	250	300	310
P	600	700	500
S	1300	1600	950
T	400	500	110
U max	400	570	400
XX	1365	1750	1027
YY	1120	1400	810
Z	675	840	550
Luik x	1650	2150	1250
Luik y	1200	1700	100

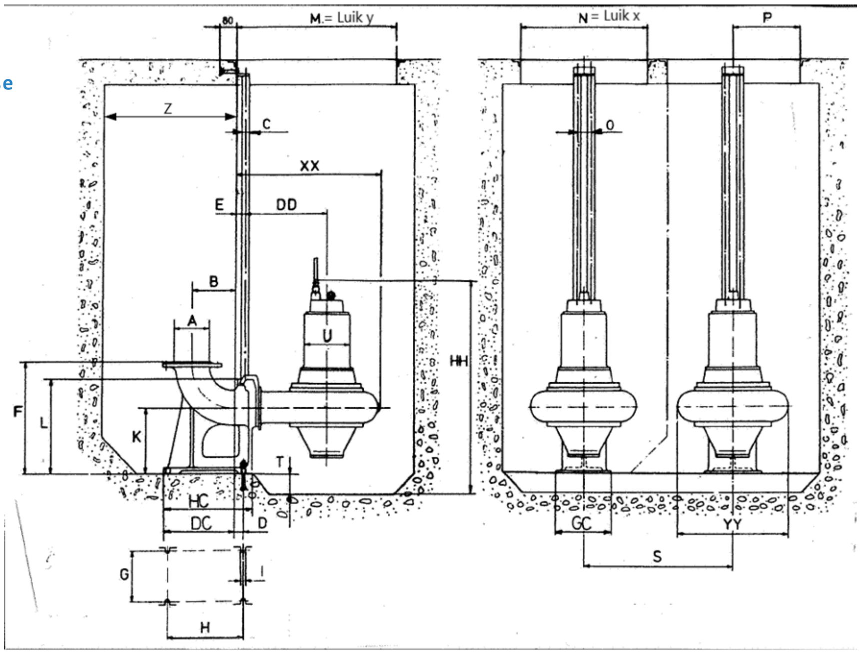


Figure 13: Pump parameter reference image

Table 7: Krooshek parameter database

Parameter Name	Vastkrooshek	Kettingreiniger
Angle	25	15
Added distance	422	798,5

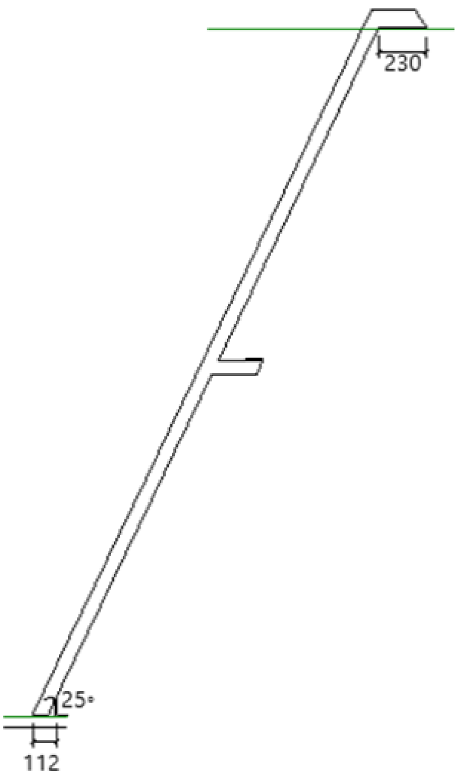


Figure 14: Reference image Vast Krooshek

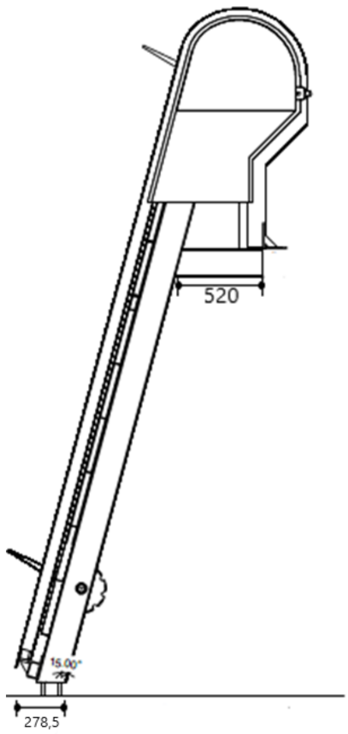


Figure 15: Reference image Kettingreiniger

4.4.4 CALCULATED PARAMETERS

The final group of parameters consists of calculated parameters based on other parameters. These parameters must be processed in VIKTOR before they are applied to the Revit File. The first two parameters that need to be calculated are the Instroom- and Uitstroomconstructie widths. The width refers to the distance between both ends of the retainment walls. The widths of the Instroom- and Uitstroomconstructie are represented in Figure 16 as parameters A and B, respectively. The heights of both the Instroom- and Uitstroomconstructie areas are also depicted in the same Figure, denoted by letters C and D. The heights depend on the top and bottom floor levels filled in on the Excel spreadsheet. The clearance distance of the krooshek is indicated by parameter E. The added distance per krooshek type, the inclination angle, and the height of the Instroomconstructie influence this parameter. The length of the Instroomdek (Instroom_instroomdeklenght_y, labelled as parameter F) is determined by the distance from the krooshek to the hatch, the y-dimension of the hatch, and the distance behind the pump (PompZ). Lastly, the length of the Instroomconstructie must be determined, representing the distance from the front of the Instroomconstructie to the back of the rear wall of the inlet structure.

Table 8: Calculated parameters

Parameter Name	Units	Formula	Reference
Instroom_breedte	mm	Calculated In map view with distance between points	A
Uitstroom_breedte	mm	Calculated In map view with distance between points	B
Instroom_heigth	mm	$= (InstroomBordeshhoogteZ - InstroomVloerhoogteZ) * 1000$	C
Uitstroom_heigth	mm	$= (UitstroomBordeshhoogteZ - UitstroomVloerhoogteZ) * 1000$	D
krooshek_y	mm	$= (tan(anglekrooshek) * InstroomHeight) + AddedDistance$	E
Instroom_Instroomdeklength_y	mm	$= KrooshekNaarLuik + LuikY + PumpZ + InstroomWanddikte$	F
Instroom_length	mm	$= DistanceToSponning + SponningY + DistanceSponningToKrooshekY + KrooshekY + KrooshekToLuikY + LuikY + PompZ$	G

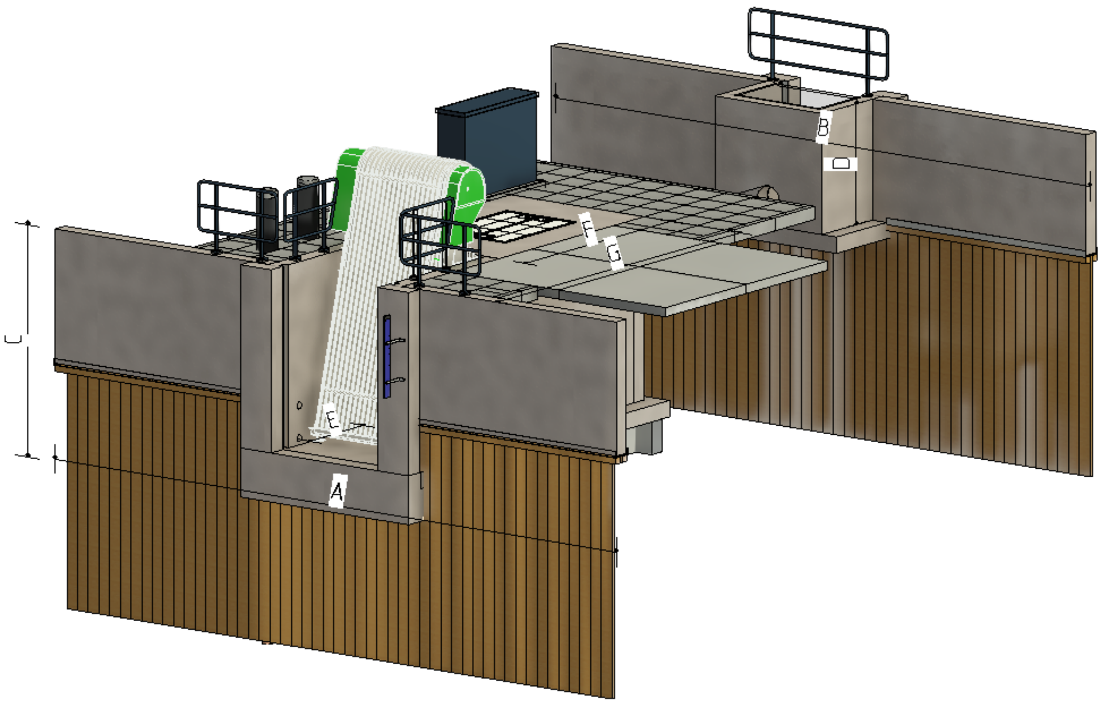


Figure 16: Reference image calculated parameters.

5 DEVELOPMENT OF PARAMETRIC MODELING TOOL

The subsequent chapter delves into a comprehensive analysis of the development process of the Gemalen Tool and its ultimate deliverables, as previously outlined in the methodology. A visual representation of the tool's structure is presented in Figure 17, depicting a flowchart highlighting the key components. As expounded upon in the methodology and depicted in Figure 17, the Gemalen Tool primarily comprises two essential elements: a User interface responsible for generating a comprehensive list of design input parameters and a script designed to convert these design parameters into an executable Revit model. This chapter explores the intricate details of these two components, shedding light on their respective functionalities and roles within the tools' overall framework.

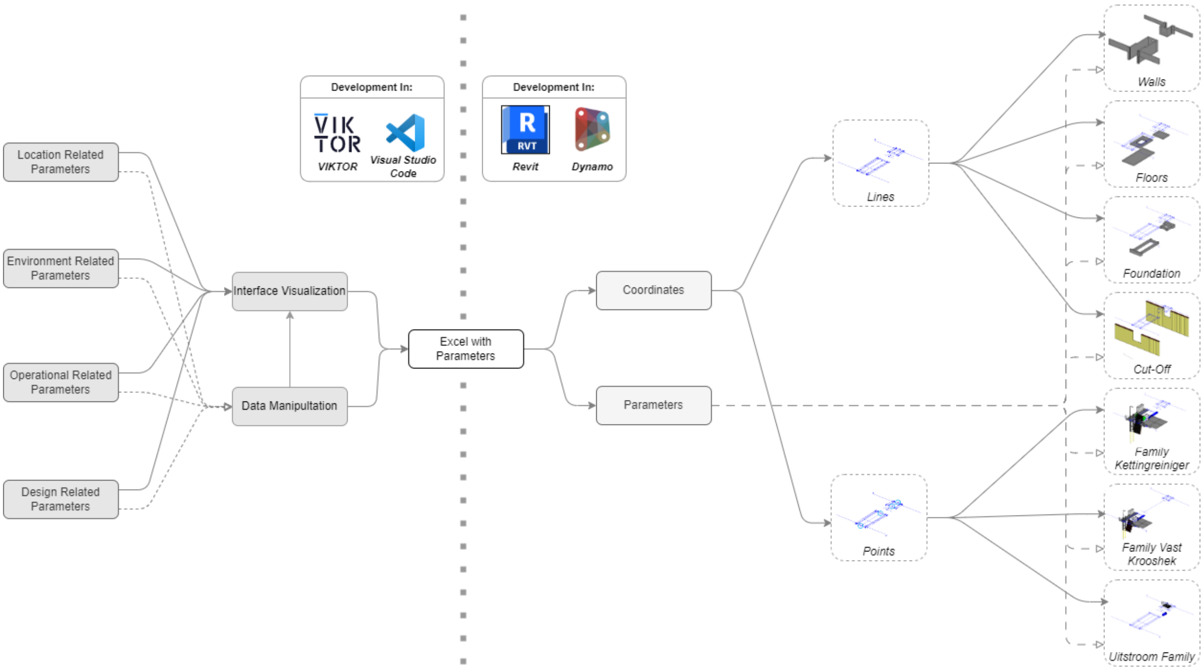


Figure 17: Development Framework Gemalen Tool

5.1 Development of User Interface

As delineated in the methodology, the iterative development of the user interface of the Gemalen Tool has been grounded in the principles of the traditional design process. The sequential design steps, delineated in Figure 18, entail systematically incorporating all parameters explicated in section 4.3 into the Gemalen Tool. The underlying configuration of the interface leverages the accessible integrations offered by VIKTOR documentation tools. Subsequently, the underlying code responsible for the tools' visual representation and data manipulation incorporated geometry limitations and translated the design knowledge and rule algorithm into parameters. This paragraph is organized into two sections. Firstly, a concise overview of the distinct steps and pages comprising the Gemalen Tool will be provided. Lastly, the Excel table will be introduced, accompanied by a summary of its contents.

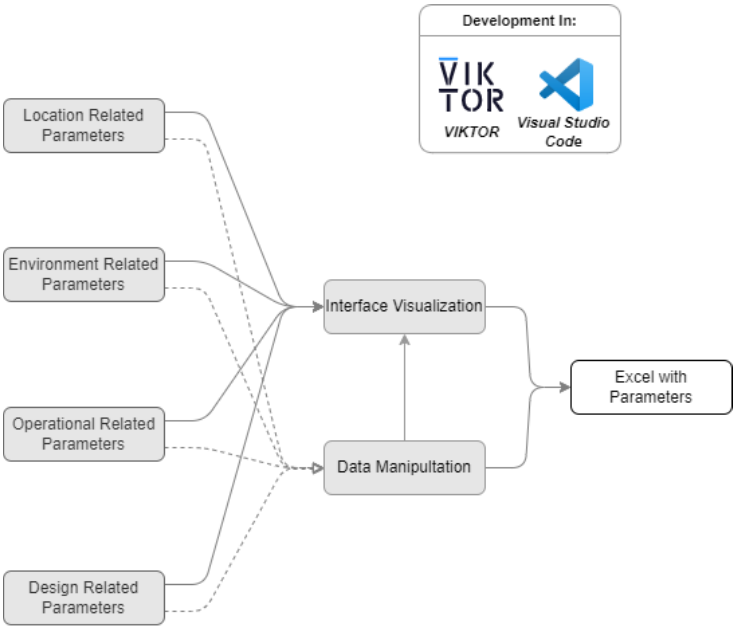


Figure 18: Development framework user interface

5.1.1 THE GEMALEN TOOL

In this section, the components of the Gemalen Tool will be explained step by step. The step pages consist of two components: an interface where parameters can be filled in on the left side and an informative section on the right-side containing maps, visualizations, and reference sheets.

Step 1; Introduction *(Dutch: Introductie)*

The initial page of the Gemalen Tool consists of an informative tab where a brief explanation of the tool is provided. At the top, the various steps involved in using this tool are displayed. By clicking on the “Volgende stap” button on the bottom right, the user proceeds to the next step.

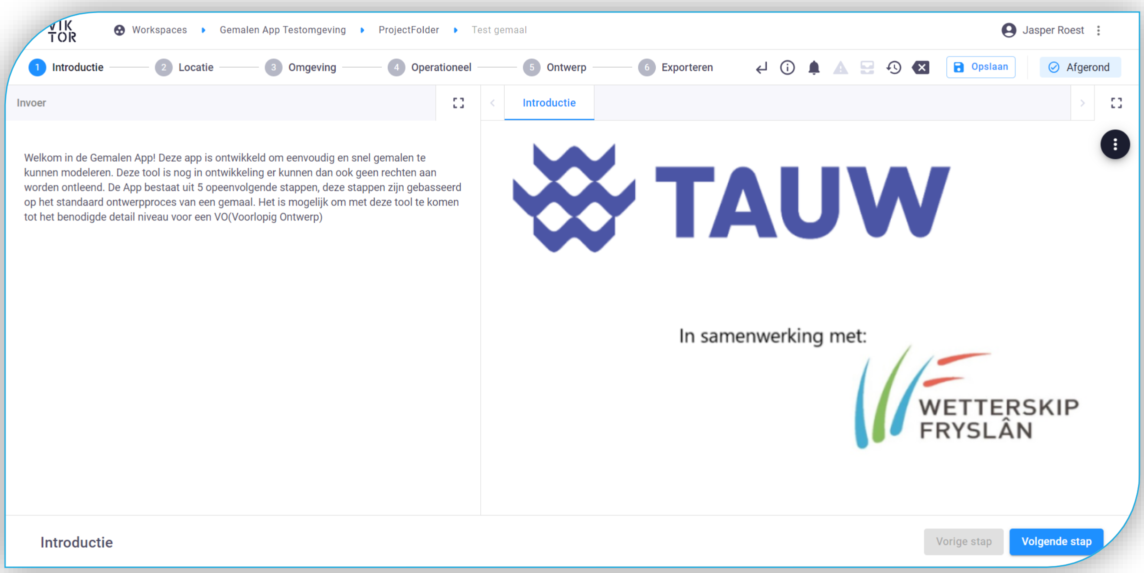


Figure 19: Screenshot of Step 1 Gemalen Tool

Step 2: Location *(Dutch: Locatie)*

In step 2 of the Gemalen Tool, the user can first enter the name of the water pumping station. Next, the user can select the location of the water pump station by using the interactive map on the right side of the interface. They can search for the location and zoom in until they have a clear view of the intended location of the water pumping station. Once the user has found the desired location, they can draw a line on the Instroom- and Uitstroomconstructie by clicking on the map. Both lines should be drawn from the perspective of facing the front of the Instroom- and uitstroomconstructie, which means two different viewpoints. After drawing the lines, the user needs to add the coordinates by clicking the "Voeg data toe" button in the output window at the bottom left of the interface in this tab. The user can proceed to the next step by clicking the "Volgende Stap" button if they have checked the information.

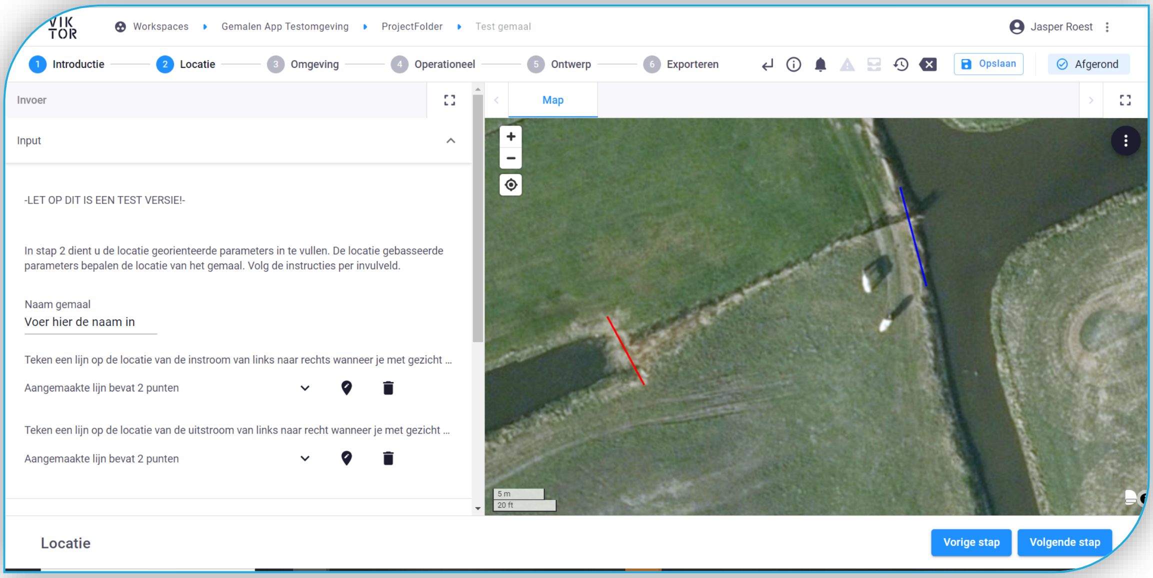


Figure 20: Screenshot of Step 2 Gemalen Tool

Step 3: Environment *(Dutch: Omgeving)*

The user can enter the operational and environment-related parameters in the designated fields in the next step. These fields correspond to the hydraulic design parameters found in the Excel spreadsheet shown in Figure 9. After entering the data in the specified fields, a visualization of the 2D layout of the pumping station is generated on the map on the right. The user can change the background map by clicking on three white dots in the black circle at the top right. Once satisfied, the user should control and add the data to the output on the left side and proceed to the next step using the designated button. If the user is unsatisfied with the layout, they can adjust the lines in the previous step. In this step, limitations have been incorporated in the interface so that the heights of both the Instroom- and Uitstroomconstructie are not too high or too low.

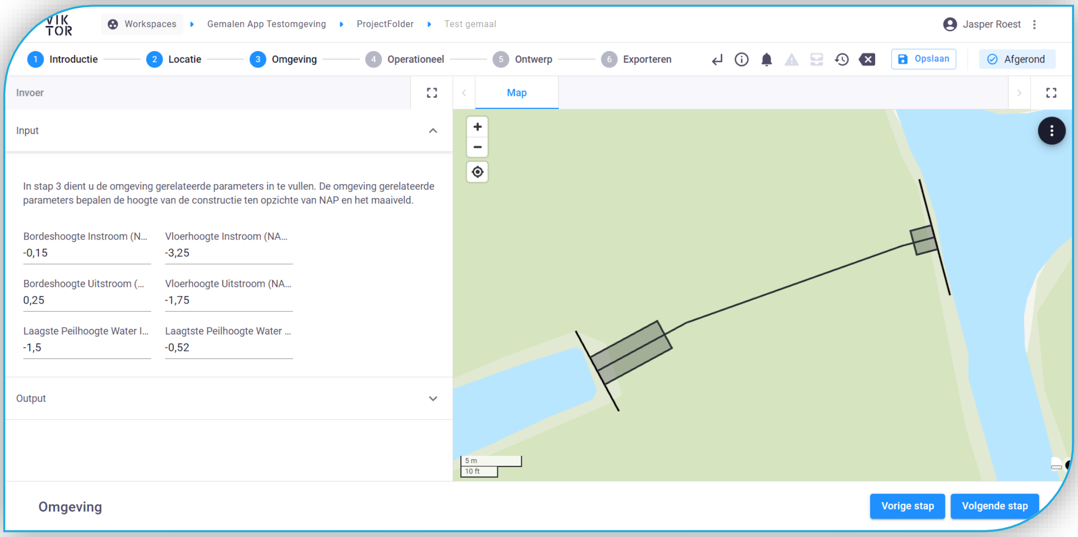


Figure 21: Screenshot of Step 3 Gemalen Tool

Step 4: Operational *(Dutch: Operationeel)*

In step 4 of the Gemalen Tool, the user is required to fill in the operational parameters, which can also be found in the Excel spreadsheet. On the right side, the map view displays the differences when adjusting parameters on the right side, and this is also reflected in a 2D visualization is similar to the previous step. In addition to the map view, a reference sheet has been included, showing the allocation of the pump parameters. After filling in the fields on the left side, the pump parameters will be displayed in the populated table when the user uploads the data. These values correspond to the values in the pump database for the selected pump. After reviewing the map view and the output table, the user can proceed to the next step. For this step, the input fields on the left have been limited to realistic values.

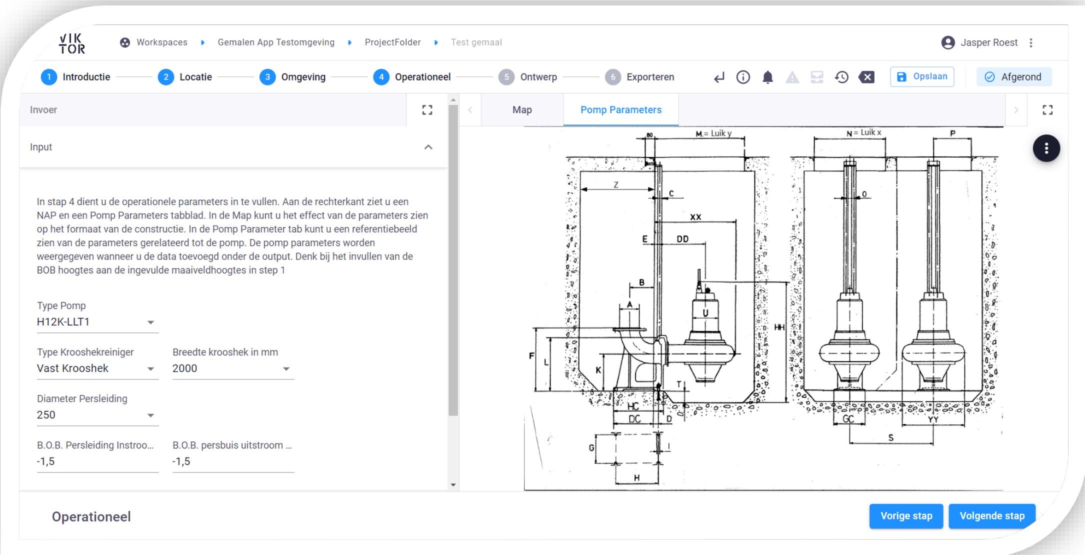


Figure 22: Screenshot of Step 4 Gemalen Tool

Step 5: Design *(Dutch: Ontwerp)*

In step 5, the remaining parameters need to be filled in. This particular step comprises two distinct components. Firstly, the parameters listed in the Excel spreadsheet are to be inputted. These parameters typically exhibit variation in the design of a water pumping station. They encompass floor thickness, wall thickness, and the inner width of the Uitstroomconstructie. Furthermore, the point depth of the seepage screen (Dutch: Kwelscherm) can be specified, thereby establishing its depth with respect to the mean sea level (NAP).

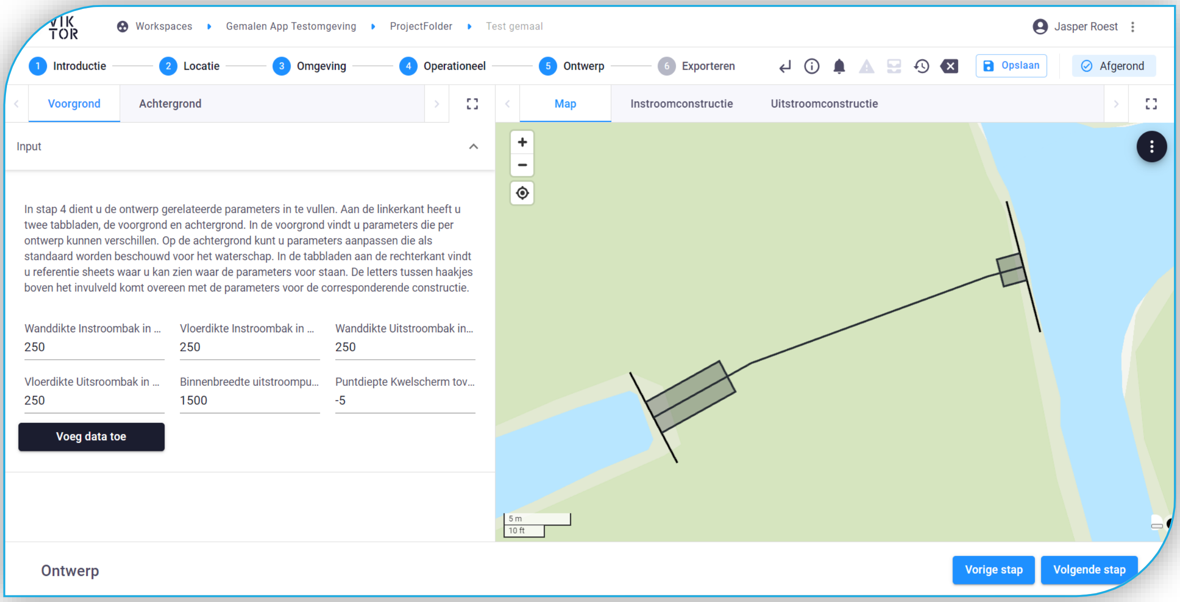


Figure 23: Screenshot of Step 5.1 Gemalen Tool

The second component of this step pertains to the background parameters. As discussed in the chapter 4.3.2, several design standardizations have been identified. These standardizations are expected to remain unchanged. However, if someone wish to modify these parameters for any reason, they can do so in the background tab of Step 5. On the left side of the interface, the standard parameters can be adjusted for each element. Corresponding refence sheets are provided on the right side, aligning with the reference sheets presented in Section 4.3.2. Once the data has been modified and thoroughly reviewed, it can be added to the database by clicking on the “Voeg data toe” button on the “Voorgrond” tab.

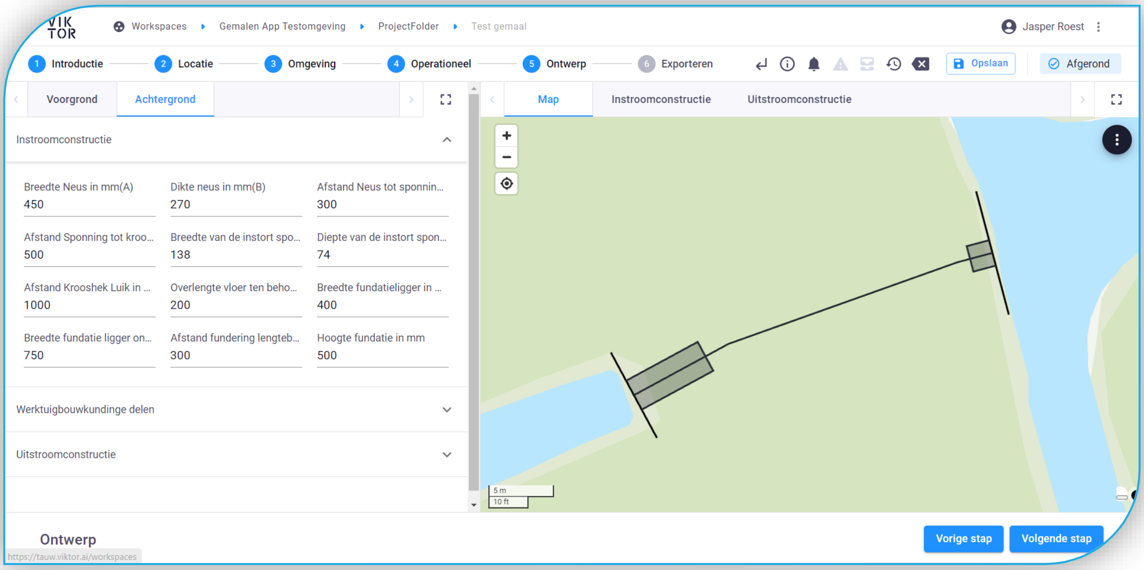


Figure 24: Screenshot of Step 5.2 Gemalen Tool

Step 6: Export *(Dutch: Exporteren)*

In the last step, the user is provided with an opportunity to review all the data and ensure its accuracy before exporting the Excel file. This serves as the last verification step prior to the user's download action. Once the review is completed, the user can proceed in this step to download the Excel file containing the parameters, the Revit template for running the Dynamo script, and the Dynamo script itself. By clicking on the black buttons located at the bottom of the table, the files are downloaded.

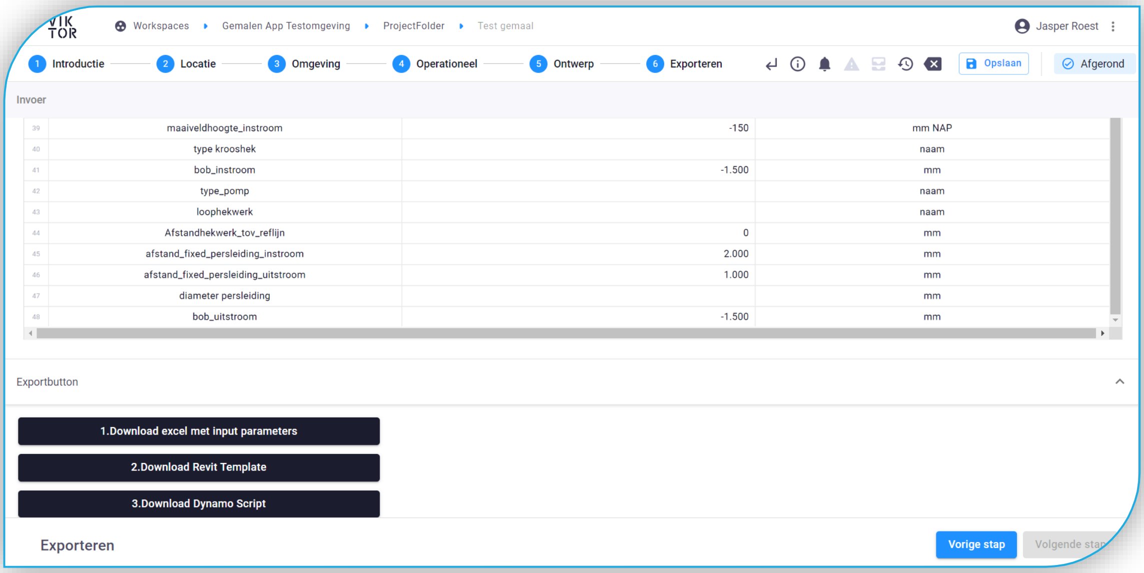


Figure 25: Screenshot of Step 6 Gemalen Tool

5.1.2 THE EXPORTED EXCEL

After completing the steps in VIKTOR, the Excel sheet that contains the parameters has been downloaded. The Excel sheet consist of two tabs: one tab for coordinates of the centrelines of both the Instroom- and Uitstroomconstructie, and another tab for the parameters. The parameter names are structured as described in Section 4.3, with the addition of a separate column for the element name. The tables below display a screenshot of both of the tabs of the exported table.

Table 9: Exported Excel Coordinates Tab

A	B	C
xy_coordinate_midpoint_instroom	207941,2871	473422,2262
xy_ coordinate_endpoint_instroommidlin	207936,0125	473418,9652
xy_coordinate_midpoint_uitstroom	207854,5738	473399,0706
xy_coordinate_endpointd_uitstroommidli	207855,9824	473400,1423

Table 10 Exported Excel Parameter Tab

A	B	C	D
instroom	bordeshc	0	mm NAP
instroom	vloerhoc	-4000	mm NAP
instroom	hoogte_i	4000	mm
instroom	lengte_in	6201,3	mm
instroom	binnenbr	3000	mm
instroom	wanddikt	500	mm
instroom	vloerdikt	500	mm
instroom	sponning	138	mm
instroom	sponning	74	mm
instroom	dikteneu	270	mm
instroom	breedten	450	mm
instroom	voorkant	300	mm
instroom	sponning	500	mm
instroom	krooshel	1870,3	mm
instroom	krooshel	1170	mm
instroom	luik_instr	1250	mm
instroom	luik_instr	1000	mm
instroom	afstanda	1037	mm
instroom	instroom	3557	mm
instroom	fundatiel	400	mm
instroom	fundatiet	750	mm
instroom	hoogtefu	500	mm
instroom	waterpeil	-3000	mm NAP
instroom	peildiepte	-100000	mm NAP
instroom	breedte_	59131	mm
instroom	overleng	200	mm
instroom	afstandfu	300	mm
uitstroor	bordeshc	4000	mm NAP
uitstroor	vloerhoc	0	mm NAP
uitstroor	maailvelc	4000	mm NAP
uitstroor	laagstew	1000	mm NAP
uitstroor	wanddikt	100	mm
uitstroor	vloerdikt	100	mm
uitstroor	binnenbr	3000	mm
uitstroor	achterka	1500	mm
uitstroor	breedten	520	mm
uitstroor	dikteneu	270	mm
uitstroor	breedte_	60844	mm
instroom	maaiveld	0	mm NAP
werktuigt	type kroc	Krooshe	naam
instroom	bob_inst	-1000	mm
werktuigt	type_por	F10K	naam
hekwerk	loophek	Langs he	naam
hekwerk	Afstandh	100000	mm
persleidir	afstand_	2000	mm
persleidir	afstand_	1000	mm
persleidir	diameter	500	mm
uitstroor	bob_uits	3000	mm

5.2 Dynamo to Revit

After generating the Excel file containing both the coordinates and parameters, they need to be transformed into a 3D model in Revit. The transformation of coordinates and parameters to 3D model in Revit, can be broadly divided into two parts. Firstly, all elements are placed based on the input coordinates and the lines drawn based on these coordinates. The second part involves adding the parameter data to the to be placed elements. In this section, these two components of the processing process in Dynamo will be briefly explained. A conceptual representation of the process is depicted in Figure 26.

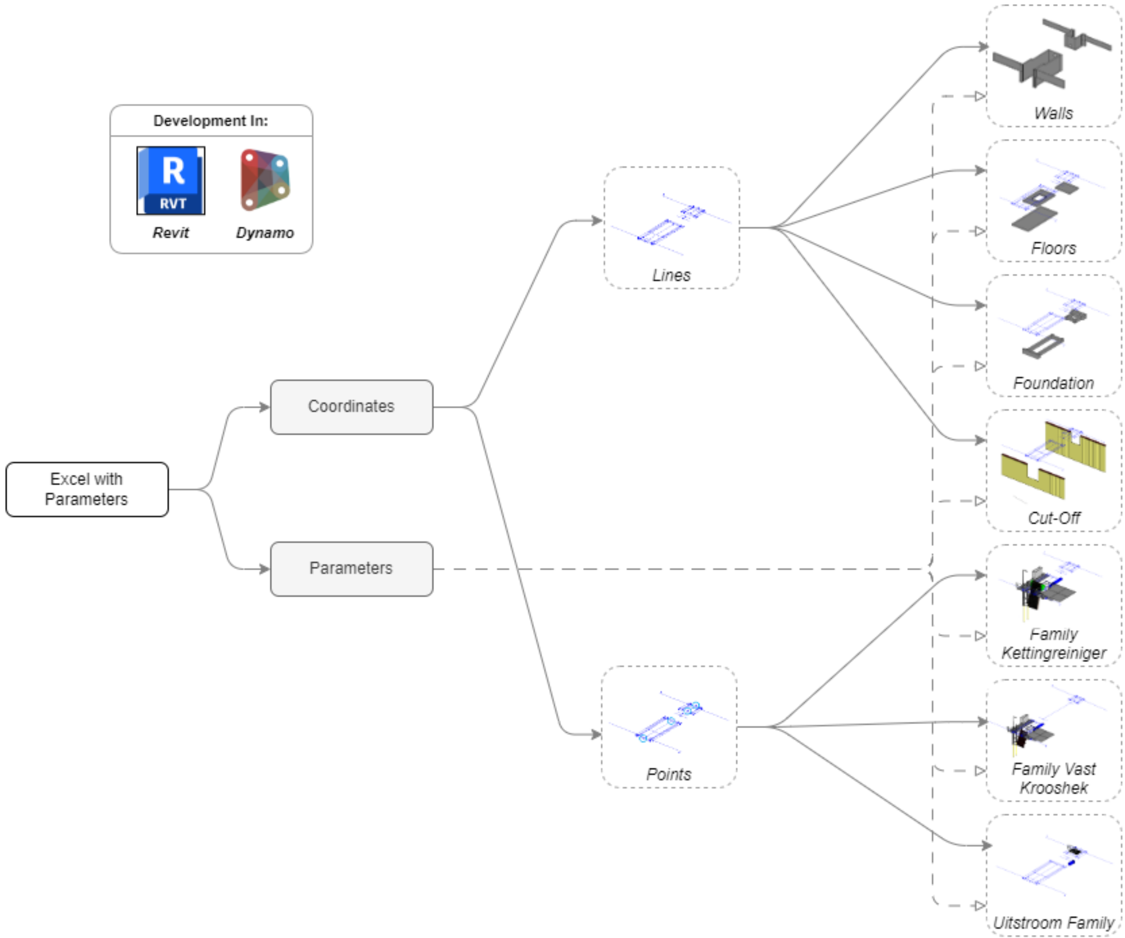


Figure 26: Conceptual framework of Dynamo Script

5.2.1 PLACING FAMILIES USING COORDINATES

As mentioned earlier, the Dynamo script can be divided into two main parts. The first part involves placing elements based on the coordinates from the Excel sheet. The coordinates from the Excel sheet correspond to the points shown in Figure 27. Based on these points, centrelines are drawn by the Dynamo script for placing elements such as walls, floors, foundations, and cut-offs. Retaining walls area also included under the walls category, as they have the same wall thickness as the Instroom- and Uitstroomconstructie. For placing the cut-off screen, points have been positioned along the drawn line, and families of planks are rotated in the correct direction.

In addition to placing the elements along the drawn lines, there are also components placed solely based on the coordinates. Depending on the choice of krooshek, the appropriate krooshek family is placed along with the family for the Uitstroomconstructie, using the coordinates in the middle of the Instroom- and Uitstroomconstructie. For now, a combined family has been created in Revit for all elements in and around the Instroom- and Uitstroomconstructie, for the sake of convenience in parameter adjustments. There are two different families for the type of krooshek, as the type of krooshek determines the dimensions of the Instroomconstructie. The combined family includes the krooshek, terreinverlichting, niveaumeetbuizen, E-kast, Leuningwerk, Krooshekleuning, Pomp installaties, and a small section of the Persleiding.

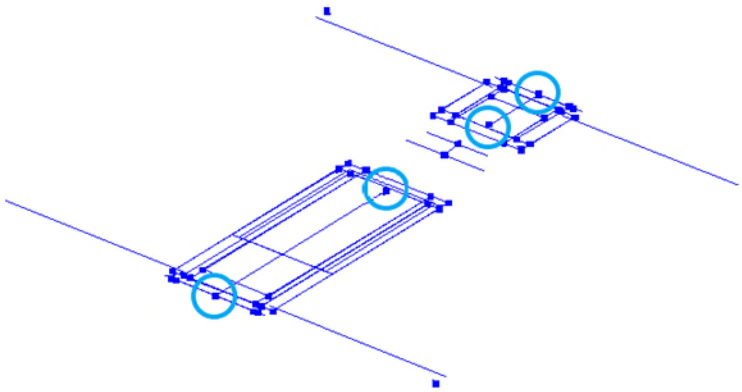


Figure 27: Points and Lines Used for the placement of families.

5.2.2 ADJUSTING FAMILIES USING PARAMETERS

The second part of the Dynamo script involves modifying the placed families base on the parameters derived from the exported Excel table. In Dynamo, all data is retrieved from this table, and by using the Dynamo node "Element.SetParameterByName," the parameters values can be assigned to specific family parameters in Revit. Since most families have been developed custom, the parameter names in the families align with the parameter names in the Excel sheet. Prior to adding the parameters through the script, some calculations have been performed in Dynamo. The intention was to minimize the calculations in Dynamo since they are not visible to the user, as the user only sees the output model. This is in contrast to VIKTOR, where the user has visibility of all parameters before downloading the Excel sheets.

6 VALIDATION

This chapter focusses on the evaluation and validation of the Gemalen Tool. The Gemalen Tool has been validated based on the validation criteria discussed in Section 3.3. The questions formulated in Section 3.3 were presented to the participants during the evaluation rounds. The second method of validation is a case study, where a model created using the Gemalen Tool is compared to a model created using the traditional methods. Both models are based on the same input Excel spreadsheet. The water pumping station used for validation purposes is the water pumping station named Ald Mar.

6.1 Results Survey Validation Criteria

The table below presents the results of the survey conducted after the testing and evaluation sessions of the Gemalen tool held at both TAUW and WF. Six participants took part in the session at TAUW, while four participants were involved at WF. During the testing sessions, participants were given the opportunity to work with the Gemalen Tool individually or in groups. Following the testing sessions, a collective discussion took place, after which the participants were required to complete a survey. The table below provides insights into the survey results. In the right column, the modus is presented which represents the most occurring survey responses.

Table 11: Survey results

Efficiency		Traditional Process	Gemalen tool				
Time Behaviour	*Traditional: How many design hours(approximately) are required for the development of a preliminary design using Traditional Design Practices/ the Gemalen tool?*	20,7	4,63				
		Strongly Efficient	Efficient	Neutral	Inefficient	Strongly Inefficient	Modus
Resource Utilization	*The amount of resources(effort) is utilized effectively during traditional design practices/Using the Gemalen Tool?*	2	5	3	-	-	Efficient
	The amount of resources(effort) is utilized effectively when using (not developing) the parametric modelling tool?	1	4	3	2	-	Efficient
		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Modus
Capacity	*Parametric: The maximal limits of the system input parameters meets the requirements ?*	1	8	1	-	-	Agree
Functionality		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Modus
Functional Completeness	*The preliminary design developed with the parametric modelling tool, reaches the intended elements of preliminary design?*	4	1	4	2	-	Strongly Agree Neutral
Functional Correctness	*The Parametric modelling tool reaches a detail level required for a preliminary design?*	5	1	4	-	-	Strongly Agree
Functional Appropriateness	*The parametric model is an appropriate method for the development of a preliminary design?*	2	4	2	1	-	Agree
Usability		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Modus
Appropriateness & Recognizability	*It is possible to recognize if the parametric model meet appropriate results?*	-	5	3	1	-	Agree
Learnability	*Specified users are able to learn working with the system in an effective and efficient way?*	2	6	1	-	-	Agree
Operability	*Specified users are able to operate the tool?*	1	7	1	-	-	Agree
User Error Protection	*The system prevents the user making mistakes or misinterpret the application?*	-	2	4	3	-	Neutral
User Interface Aesthetics	*The user interface of the parametric tool is aesthetically pleasing?*	-	7	2	-	-	Agree
Accessibility	*The application is operatable by any user with only little knowledge of water pumping stations?*	-	3	3	3	-	Agree Neutral Disagree

Although the survey was conducted with a limited sample size of only ten users(with one user providing incomplete responses to only the first five questions), several noteworthy findings can be derived from the survey results. As delineated in the methodology and theoretical framework, the validation criteria chosen and implemented were efficiency, functionality, and usability. Efficiency, the first criterion evaluated, encompassed sub-characteristics such as time behaviour, resource utilization, and capacity. Regarding time behaviour, the average time spent on the preliminary design process for water pumping stations was compared between the traditional practice and the utilization of the Gemalen Tool. According to the respondents, the expected time spent using the Gemalen Tool was only 4,6 hours, whereas the traditional design process requires approximately 20.7 hours. The scores for the sub-characteristic of resource utilization were similar for both the traditional process and the process employing the Gemalen Tool. Considering the results of the efficiency-related questions, it can be inferred that the Gemalen Tool significantly enhances process efficiency, particularly in terms of time consumption.

The second criterion evaluated in the survey was the functionality of the Gemalen Tool. As indicated in the theoretical framework, the Gemalen Tool need to exhibit functional qualities. Functionality was further subdivided into three sub-characteristics: functional completeness, functional correctness, and functional appropriateness. Respondents provided varying ratings for functional completeness, with nearly all respondents providing positive ratings. Similar patterns were observed for the other aspects of functionality, as the majority of respondents agreed with the functional correctness and appropriateness of the tool. Based on the respondents' answers, it can be concluded that the Gemalen Tool effectively serves its intended purpose, achieving the desired LOD and employing appropriate methods.

The final criterion assessed in the survey was the usability of the Gemalen Tool. The tool was required to be usable by individuals with some knowledge of water pumping stations. Usability was evaluated based on sub-characteristics such as appropriateness and recognizability, learnability, operability, user error protection, user interface aesthetics, and accessibility. Table 11 demonstrates that appropriateness and recognizability, learnability, operability, and user interface aesthetics received positive ratings by the respondents. User error protection elicited neutral responses, with explanations stating that while it exists in the tool, there is still considerable room for improvement in error protection within the Gemalen Tool. The question regarding accessibility also yielded mixed responses from the participants. Since they do think that knowledge is required when using the Gemalen Tool.

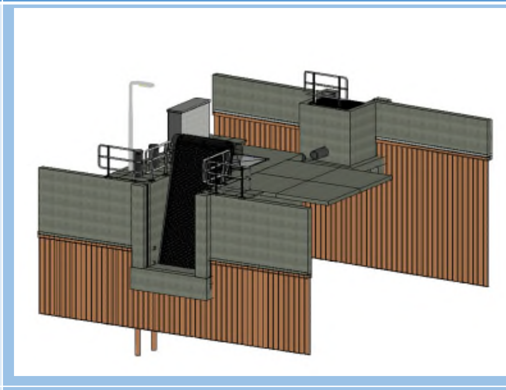
6.2 Case Study

For validating the tool through a case study, the Ald Mar case was selected. This is a pumping station managed by WF, which requires a capacity of 9,7 m3 per minute with the H12K-LLT1 pump type of Hidrostal. This water pumping station falls within the scoped range of the Gemalen Tool and is therefore suitable for model comparison. The 3D model produced by the Gemalen Tool is compared to a model produced using traditional design processes, both based on the same design input. The Excel spreadsheet containing the design assumptions is presented in Table 12. In Table 13, a summary of the results of the case study are displayed. This table includes both models, highlighting various aspects such as time required to create the model, the effort involved, the elements missing compared to the other model, and the LOD of both models.

Table 12: Excel spreadsheet with design assumptions case study

Gegevensblad nieuwbouw gemaal Ald Mar						
Adres						
Naam Object	Adres	Postcode	Plaats	ID_CODE	Rayonbeheerder	OW.nummer
Uitgangspunten						
Pomp/vijzel	Reiniger	Behuizing klein/groot	Uitvoering behuizing	Besturing	Lantaarnpaal	Hekwerk
1 x pomp	1 x Kettingreiniger	klein	Ontwerp WF	Axioline	1 x	Ambassador
Peilgegevens						
Instroompeil (zp / wp - m NAP)	Uitstroompeil (zp / wp - m NAP)	In ontwerp rekening houden met mogelijke toekomstige pompoptimalisatie	Opvoerhoogte minimaal cm.	Opvoerhoogte maximaal cm. (incl. toekomstig en verval krooshek).	Dynamische opvoerhoogte minimaal	Dynamische opvoerhoogte maximaal
-1,70 mNAP	-0,52 mNAP	20 cm	118 cm	207 cm	230 cm	267 cm
Pompgegevens						
Capaciteit m3/min	Type pomp(en)	P max. (kW)	Tpm/Hz werkpunt	Tpm 50 Hz	Voetbocht	Drooglooppeil
9,7	H12K-LLT1			725	ABS	-2,25
Vijzelgegevens						
Capaciteit m3/min	Aantal vijzels	Diameter vijzel	Vulpunt vijzel	Stortpunt vijzel	Tegenmaalpunt	Drooglooppeil
Persbuis						
Materiaal persbuis	Lengte persbuis meter	bochten	Uitstroomklep	Persbuis diameter	Stroomsnelheid persleiding	
GVK	10	3	400	400	1,36	
Instroomput						
Breedte inwendig	Bodemhoogte (NAP)	Bordeshoogte (NAP)	B.O.B. persbuis instroom	Wanddikte	Afmeting Luik	
2000	-3,25 mNAP	-0,45 mNAP	-1,4 mNAP	250 mm	1650 x 1200	
Uitstroomput						
Breedte inwendig	Bodemhoogte (NAP)	Bordeshoogte (NAP)	B.O.B. persbuis uitstroom	Lengte inwendig	Wanddikte	Afkeurhoogte uitstroom
1500	-1,60 mNAP	0,25 mNAP	-1,4 mNAP			-0,04
					Versie 1.0	

Table 13: Summary results case study

	Traditional Design Process	Gemalen Tool
		
Time	Approximitly 24 hours of designing	On average 15 minutes to fill in the table
Effort	Effort from Structural Engineer and Revit Engineer, both acquaintwit wat	Effort from someone with knowledge of waterpumping stations, or able to use the Gemalen tool.
Ellements not included	-Lightning fixture: The lighting fixture was not included in the model provi	-Fences(Dutch: Hekwerk): The Gemalen Tool cannot include fencing since it is not possible to let them change parametrically. -Surfacing(Dutch: Verharding): The Gemalen tool is not able to include surfacing surrounding whole structure -Level measuring scale: The level measuring scale at the front of the construction was not identiffied in the OTL nor the OBS. -Presure pipe (Dutch:Persleiding): The Gemalen Tool only provides the fixed parts of the Presure Pipe and not the connection between the two pipes.
LOD	250 or higher	250 or higher

At first glance, there appear to be few difference between the various models, suggesting that the tool is functional and capable of producing a preliminary design model. However, a closer examination of the elements and their incorporation is necessary to draw this conclusion. In the left model, the design was modelled in a traditional manner, with each element individually placed and the geometry shaped by the designer's actions. This approach allows for detailed elaboration of the model but also increases the risk of human errors. This was evident in the model, where some dimensions had non-rounded values that are not achievable with such precision in reality. In the right model, the potential for human error lies in selecting the correct parameter values. However, once the appropriate parameters are inputted, there are no unexplained dimensions in the model, and all dimensions conform realistic values corresponding to the objects.

Based on the survey results, there was some ambiguity regarding the time behaviour of the tool and the traditional process, resulting in significant variations in the responses provided. When examining the test sessions with the experts, it took approximately 15 minutes to use the tool, whereas the traditional design process for the model in the case study took approximately 24 hours, according to WF's civil designer.

Visual differences, such as the colours of the model, can be attributed to the material choices in Revit and do not provide any information about the level of detail. However, it can be said that some elements in the left model have higher LOD compared to those in the right model. This is because certain parts of the left model are tailor-made for the modelled pumping station and were provided by the component supplier. Examples include the krooshek and the kwelscherm planks. Achieving this LOD in the model generated by the tool was not feasible due to the significant time required. However, the model generated by the tool can be easily modified, which may enable increasing the LOD in the future.

Based on the two applied validation methods it can be concluded that the Gemalen Tool proofs the concept of parametric modelling for water pumping station. It can be concluded that using the tool for generating a preliminary design for water pumping stations has higher process efficiency than the traditional design practice and is usable and functional for its purpose.

7 DISCUSSION

Despite the research progressed according to plan and successfully achieved not only a proof of concept but also developed a framework for parametric modelling tool, there are certain limitations that need to be assessed. This chapter describes these limitations by examining three distinct aspects: limitations to the research, limitations of the applied methodologies, and limitations of the tool itself.

7.1 Limitations of the research

The researched focused on developing a framework for parametrization of water pumping station based on the development process of a parametric modelling tool for water pumping stations. A proof of concept was used as a benchmark to assess the functionality of the framework, guided by selected validation criteria. These criteria were determined through discussions with potential users from a single company, WF. Ideally, these criteria would have been selected based on a sector-wide investigation involving users from various companies. However, this was not feasible within the time constraints of this research. Additionally, there is no existing framework available for validation similar tools to the Gemalen Tool. Testing the developed framework on other parametric modelling tools is required to substantiate the proven applicability.

The next point of discussion is the operationalization of the validation criteria. As mentioned earlier, the validation criteria were chosen based on user preferences of users of a single company. Then, academic literature and practical documentation were examined to identify methodologies for investigating these criteria. ISO-25010 was selected because it encompassed all three criteria. However, alternative, and potentially more widely used methods for testing efficiency, usability and functionality in surveys were available for operationalizing the criteria. Furthermore, multiple methodologies could have been combined to formulate the survey questions. In addition, the ISO-25010 methodology is broader than only efficiency, usability, and functionality. It also includes compatibility, reliability, security, maintainability, and portability, which can be tested in the future.

The last point of discussion regarding the research pertains to testing and validation of the tool. Due to time constraints, the testing and validation process was limited to ten respondents. Ideally, the tool would have been tested more extensively during this phase, and there would have been a larger number of survey responses. The limited number of respondents resulted in drawing conclusions from untested data for validation purposes. With a larger number of respondents, the questions could have been statistically tested, leading to potentially more robust conclusions. Besides that, the case study consisted of one model only. In order to further validate the Gemalen Tool, the tool should be tested to multiple models.

7.2 Discussion of the Applied Methods

Various methodologies were employed during the various phases of the development of the Gemalen Tool. Considering that the research aims to establish a framework, it is important to briefly evaluate the methodologies used. The first methodologies applied were OOM approaches OTL and OBS. Initially, the widespread use of OOM was not immediately perceived as positive by participants in the exploratory discussions. This deviated from the traditional mindset of the participants in the expert meetings, who viewed a pumping station more as a structure connected to the environment. However, after thorough explanations were provided regarding the decomposition of a water pumping station into objects, participants began to recognize its added value. Furthermore, the OOM approach served as a solid foundation for the element-based development of the tool. As part of the OOM method, an OTL was created, utilizing the existing OTL developed by Waternet. While searching for object definitions, it may have been beneficial to explore other OTLs more thoroughly as well. By considering alternative definitions, a more robust OTL could have been created. However, the use of the OTL methodologies facilitated a shared conceptual perception of the definitions. The creation of the OBS went hand in hand with the development of the OTL. The NEN-2767 methodology for decomposition proved universally applicable for constructing OBSs, since they provided a clear overview and logical aggregation levels.

For both the user interface in VIKTOR and the script in Dynamo, the DevOps methodology was applied. The steps of DevOps are suitable for developing programs like the Gemalen Tool. However, the DevOps method is primarily focused on collaboration among separate roles within the development process. Since the Gemalen tool was developed solely by one individual, there was no collaboration within the project between different software departments. Nevertheless, going through these steps is beneficial even when the code is developed and reviewed by the same person. If multiple individuals were involved in the development process of a tool, the advantages of utilizing the DevOps methodology would be further amplified.

7.3 Limitations of the tool

In order to enhance the feasibility of tool development within the given time constraints, delineations have been incorporated for each step. During the exploration meeting concerning parametric modelling of water pumping stations, the idea of selecting surface levels, water levels, and soil types based on locations was considered. However, inclusion of interactive map data has been excluded from the scope due to the recognized complexity involved in developing software code for integration of map data.

For the hydraulic design aspect, a choice has been made to select three pump types, which are based on the preference of WF. WF has preferred supplier of pumps, Hidrostal, who serves as their primary supplier. The three selected pumps are installed in the majority of water pumping stations in their acreage. Additionally, the model only incudes two types of trash racks(krooshekken), a fixed type (vast krooshek) and a trash rack cleaner(krooshekreiniger). These water plant restricting devices are standard for WF and represent the most commonly used types in their designs. The development of the parametric model focusses on the standard design of water pumping stations within the range of 5 to 15m3 per minute for WF. Specific design choices unique to WF have been incorporated into the tool. Initially, the tool will be applicable to water pumping stations constructed according to the standards set by WF. Expanding the scope at this stage would result in less detailed models that are less suitable for WF needs.

During the decomposition stage, a thorough evaluation was conducted to determine the elements that should be incorporated into the tool. The objects identified in the OBS represent the fundamental components of a water pumping station for WF. The primary objective was to include as many of these identified elements as possible in the model. However, due to time limitations, the goals were adjusted to what could be achieved within the restricted period of this research project. The model was designed to incorporate essential components, which are the components necessary to achieve a level of detail appropriate for a preliminary design. Examples of essential components include the “instroombak” (inlet basin), pump, “krooshek” (trash rack). Together with the cooperating experts of TAUW and WF, the exclusion of elements has been discussed thoroughly. Figure 28 provides an overview of all the objects in the OBS and indicates whether they are included, partially included, or excluded from the parametric model.

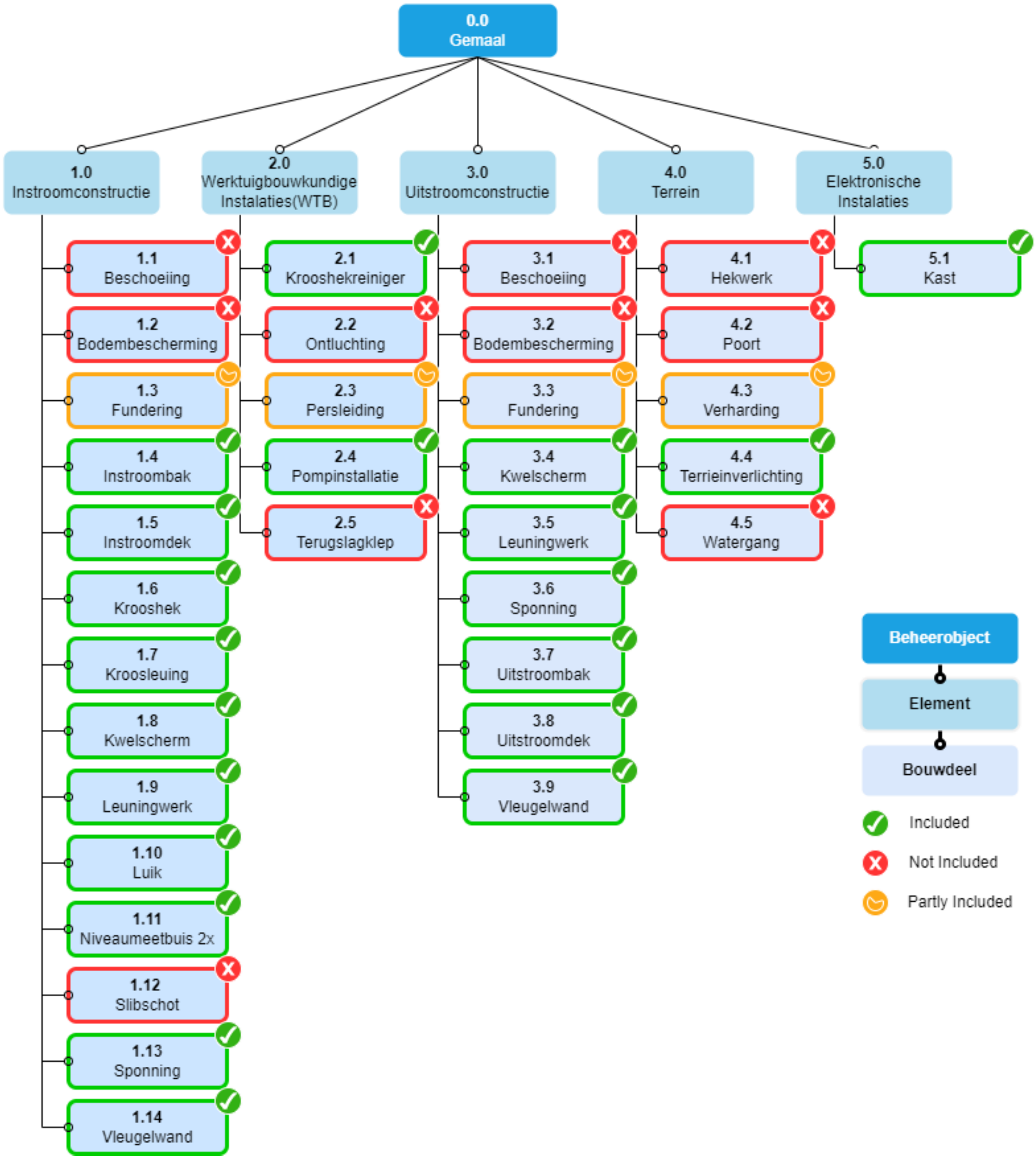


Figure 28: OBS with included, partly included, and excluded objects.

8 CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

This report delves into the research aimed at answering the main question: “How to develop a parametric model for the preliminary design of water pumping stations? Parameterizing water pumping stations can contribute to the current challenges in the construction sector. Given the shortage of skilled professionals and the substantial need for replacements, there are benefits to automating the design process. Parametric design presents an obvious method for design automation, wherein relationships between various components of a design are encoded in an algorithm. Parametric design is a viable option for water pumping stations due to their highly repetitive design, complex yet non-unique nature, and the need for flexibility throughout the design process. By utilizing a parametric modelling tool and inputting a few parameters, unique design models can be generated quickly. This research explored the development of the Gemalen Tool, wherein various methods were tested to establish a framework for parametrizing structures such as water pumping stations. To achieve success, the Gemalen Tool must be usable and functional, enhancing efficiency.

To investigate various applicable methods, an extensive literature review was conducted. Firstly, exploring parametric modelling in general and then its application in developing the Gemalen Tool. The literature review revealed a lack of research on parametric modelling specifically for small civil projects, despite its potential. According to the literature, acquiring design knowledge of the elements comprising the design structure is crucial for parametric modelling. Additionally, studying the underlying rule algorithm is necessary for creating a parametric model. To address these two aspects, research was conducted to identify methods that can contribute to the study. OOM methods, OTL and OBS were identified as methods to improve understanding of the design object and its interrelationships. The parametric mode was created in the VIKTOR program environment. For the development of the software, DevOps have been applied.

After decomposing a water pumping station into objects, research was conducted on their interrelationships and design grammar. The initial input for the development of the tool was based on the WF Excel spreadsheet, combined with practical documentation. This resulted in the following comprehensive design steps. First, the location needs to be determined. Then, the flow of the water is determined by considering parameters dependent on the surrounding environment. Next, operational choices, including selection of pump type a trash rack, need to be made. Finally, the remaining civil design parameters that define the ultimate design are filled in. These steps had to be incorporated into the design of the Gemalen Tool. The parameters influencing the design included those from the Excel spread sheet, databases of mechanical equipment, standardized design parameters, and calculated parameters.

Subsequently, the research involved the development of the Gemalen Tool, consisting of two components: the development of a user interface in VIKTOR and the design of a script in Dynamo that converts the parameters into a 3D model in Revit. The designed VIKTOR interface is built upon the design grammar mentioned din the previous section. In the background of the user interface, the code is written in VSC processes and calculates the calculated parameters. The limitations of the geometry of the objects are also defined in the VIKTOR environment. The Dynamo script involves placing objects based on coordinates and assigning parameters to these objects. By adding the parameters, the geometry is determined, while the coordinates determine the placement of the objects relative to the real environment and each other.

The ultimate step of the research involved the validation of the Gemalen Tool. This was done through testing sessions, a survey, and a case study, where a model generated with the Gemalen Tool was compared with a model created in the traditional manner. The survey indicated a positive reception of the Gemalen tool, as it reduced the time required and was deemed usable and functional. The case study revealed that both models were almost identical, with only a few minor differences. Despite some missing elements in the model generated by the Gemalen Tool, it can be concluded based on the research that it has achieve a proof-of-concept status. Therefore, it suggested that the methods used in this research can contribute to the development of other parametric tools for similar constructions.

To conclude the report, the main research question must be answered in a clear and concise manner. It has been possible to develop a parametric modelling tool by applying and testing various methods. By employing methods such as OOM and DevOps, it has been feasible to arrive at a clear and reproducible approach for creating a parametric modelling tool for water pumping stations. The proof of concept developed using these methods has proven to be usable according to the predefined criteria. The tool is more efficient than the traditional approach and remains usable and functional throughout its operation. The applied an tested methods, along with the detailed reasoning and structure incorporated into the development of the tool, can collectively be seen as a framework for developing other parametric modelling tools. Together, the Gemalen Tool and other future parametric modelling tools can contribute to addressing the current challenges prevailing in the construction sector.

8.2 Future research

As revealed in the research, there has been little investigation into parametric design of civil structures to date. Nevertheless, it is widely discussed in the market as a potential mean to meet the impending excessive demand. Therefore, further research can be conducted on the applicability of parametric design within the sector. Additionally, exploring payment mechanisms for parametric modelling tools is important, as working with parametric design differs from the traditional practices in consultancy firms where billing is often based on billable hours.

Within this research, a framework was attempted to be created for parameterizing the design of small civil structures through a case study. Several methods were deemed applicable within this study: however, this does not guarantee their suitability for other civil structures. Therefore, it is recommended to investigate the application of the developed framework for the development of other programs. Further research can also be conducted to explore the usability of these methods. For example, in the case of DevOps and validation criteria based on ISO 25010, not all aspects of the methods were fully implemented. Due to the limited available time, there was no opportunity to explore the operate and monitor phase of DevOps, which involves testing the tool’s functionality over a longer period. This aligns with the parts of the ISO 25010 method for quality evaluation that were not considered. In the long term, the quality evaluation method could include testing compatibility, security, maintainability, reliability, and portability to access whether the Gemalen Tool is truly a quality product. This could be investigated in future studies.

As mentioned in the discussion, the Gemalen Tool was only tested by a limited group of users. In future research, a larger group of testers form different companies could be involved. This would provide a more comprehensive understanding of the tool's usage and users' experiences. It would be advisable to further refine and potentially enhance the tool for such studies. There is room for improvement, and feedback from surveys can be utilized for further development of the tool. Additionally, parameters can be further minimized considering alternative design assumptions.

Further development of the tool can also focus on the content of the model. As mentioned in the literature review, the drive for optimization in another reason for using parametric design. However, this aspect remained underexplored in the research. Yet, when further developed, the model may be optimized. For example, adding metadata to make the model smarter could be explored. Investigating potential enhancements would be interesting for optimizing the tools use in areas such as asset management or environmental impact assessments. Maybe developing a more comprehensive model with metadata requires different development approaches. Further opportunities is the incorporation of other disciplines in the tool. For example engineering, geotechnical and hydrology disciplines could be added to the Gemalen Tool. The number of parameters can be minimized by applying these disciplines to the design logic. However, further research is required to investigate the effect of these disciplines on the design before adding these parameters to the tool.

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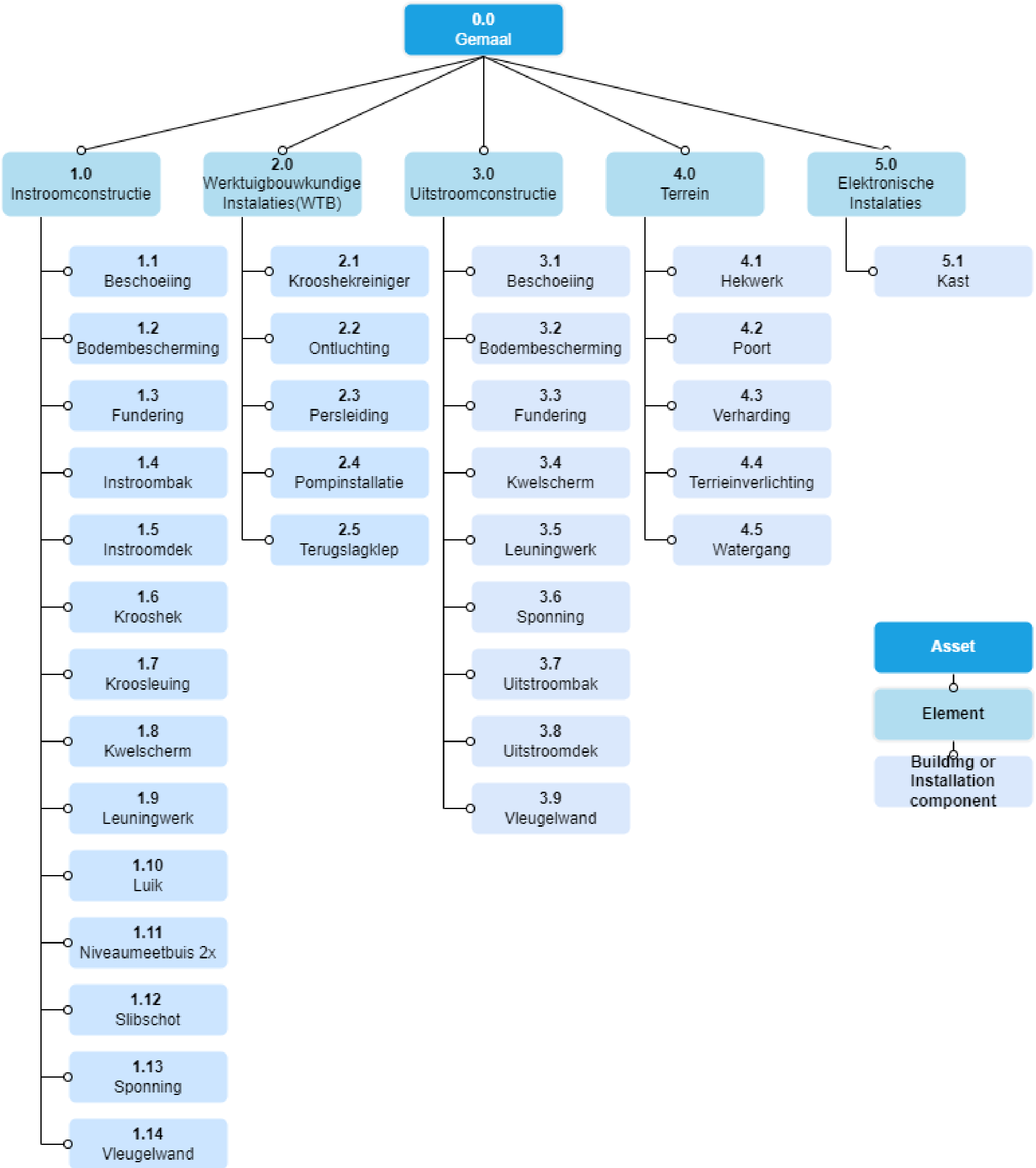
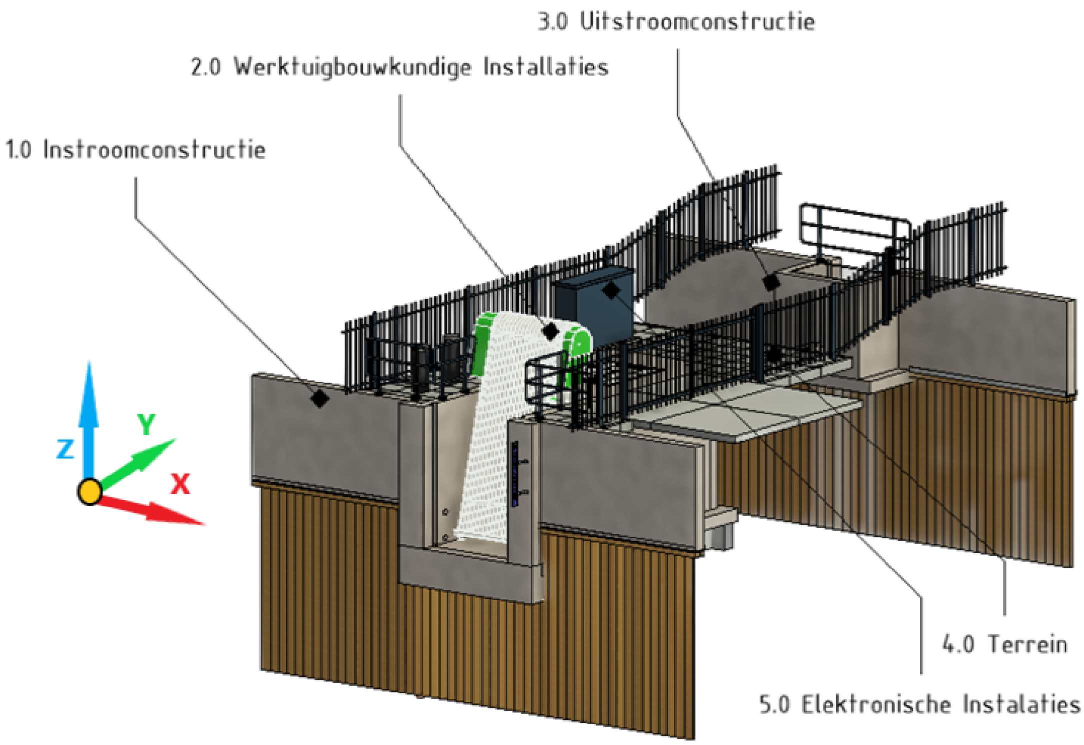
APPENDIXES

Appendix 1 Decomposition Phase

APPENDIX 1.1 OBS

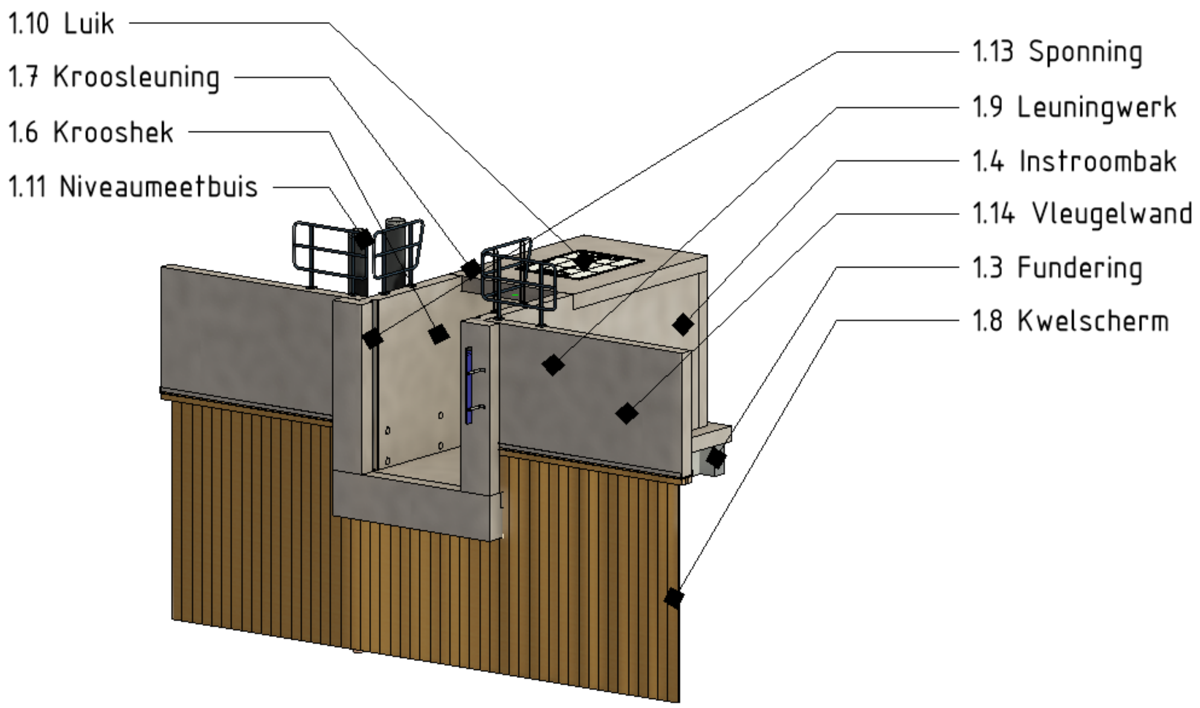


APPENDIX 1.2 VISUALIZATION OF OBJECTS AND DETAILED DISCRIPTION



1.0 Instroomconstructie

The instroomconstructie, which is located in the lower portion of the water level body, can be defined as a structure that allows water to enter the construction. Its dimensions are determined by both environmental and operational factors. The height(z) of the Instroomconstructie is dependent on the pump characteristics, as well as the retaining height and the water levels. The width dimension(x) is limited by the retaining width of the structure, which is often the width of the connected waterbody plus half a meter on both sides for a water pumping station. The y dimension of the instroomconstructie is determined by operational parameters and the placement of mechanical elements. The instroomconstructie consists of the following components:



1.0 Instroomconstructie

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1.1 Beschoeiing

Beschoeiing is connected to the water pumping station at the side of the waterbody and can be defined as a shore protection consisting of an orthogonal wall that safeguards the shore form erosion. The extent to which the Beschoeiing will be incorporated in the tool's development depends on the available time since Beschoeiing is not critical to validating the concept of the tool.

1.2 Bodembescherming

Bodembescherming is located in front of the instroomconstructie or uitstroomconstructie and can be defined as a cover that shields the bottom of the waterbody, preserving its quality. The degree to which Bodembescherming will be integrated into the tool depends on the time available, as it is not necessary to validate the tool's concept.

1.3 Fundering

Fundering is the Dutch equivalent of foundation and can be described as a structure located beneath or at ground level that distributes forces to the underlying sturdy layers if soil. The fundering is located beneath the Instroombak and is determined by the dimensions of the Instroombak. For Wetterskip Fryslân, they often place new superstructures on existing foundations. To simplify the tool's development, four foundation piles are positioned beneath each of the supporting beams of the Instroombak and Uitstroombak. However, for further refinement, the placement of the foundation piles can be optimized based on structural calculations. The ground anchors connected to the Kwelscherm are part of the fundering. Their location and dimensions are not parameterized since they are only included for reference purposes.

1.4 Instroombak

The Instroombak is the concrete pomp sump that serves as a component of the construction, preventing soil erosion and providing space for mechanical components and the pump. The Instroombak comprises walls and floors, but there are also additional special elements. At the front of the Instroombak, there is a small protruding concrete slab called "de Neus," which is located in front of the adjacent vleugelwanden. The width of the floor of the instroombak includes the width of the instroombak, the thickness of the walls, and the protruding Neus. The sponning, which will be discussed later, is cast in the instroombak just after the Neus. At the end of the instroombak, a pile-up(opstort) of concrete is situated to support the pump. The final special part of the instroombak is the notch for the instroomdek. The dimensions of the notch will be clarified in the next bullet point. A with the instroomconstructie, the dimensions of the instroombak depend on the retaining height, landscape, water levels, and the space required for the pump and other mechanical parts. Often, standardization is applied to the widths of the instroombak, this standardization arises from sponningen and kroosrek with standard widths.

1.1 Instroomdek

The instroomdek is located above the instroombak in the designated notch and can be defined as a construction element that covers the instroomconstructie. The dimensions of the instroomdek depend on the pump-related dimensions and the dimensions of the chosen hatch (Luik). Another influencing parameter is the required operation distance behind the krooshek.

1.2 Krooshek

The krooshek is an angled fixed fence that prevents debris and water plants from flowing into the structure and damaging the installations. It is located in the instroombak at a designated distance behind the sponning. During maintenance, slibschotten (1.12) are placed in the sponning so that the instroombak can be emptied using pumps. A designated place has to be taken in consideration in the design of the instroombak. The angel and height of the krooshek affect the length of the dedicated area of the krooshek. The automated alternative of the krooshek falls under the mechanical parts (WTB installations 2.0).

1.3 Kroosleuning

The kroosleuning is a barrier located on the instroomdek that serves as support and prevents falls form heights. On this location is prevents people to come in contact with the krooshek or krooshekreiniger. It is positioned behind the krooshek and krooshekreiniger on the instroomdek. The width of the kroosleuning is determined by the width of the krooshek or krooshekreiniger.

1.4 Kwelscherm

The Kwelscherm is located beneath the instroombak, uitstroombak and vleugelwanden and serves as a vertical, impermeable structure that retains water flows. Various materials and techniques can be used for the construction of a Kwelscherm. Wetterskip Fryslân employs a pine Kwelscherm consisting of planks and two connecting beams for the water pumping stations in the designated range of water pumping stations. The width of the Kwelscherm is determined by the width of the retaining vleugelwanden.

1.5 Leuningwerk

The Leuningwerk is situated on the vleugelwand within the verharding and in between the hekwerk leuningwerk is situated that serves as support and prevents falls from heights in the waterbody. The width is dependent on the dimensions of the vleugelwanden.

1.6 Luik

Luik, also known as hatch in English, is an openable horizontal plate with hinges and handles to close a sump, or hole. The hatch is situated in the instroomdek above the pump. The minimal dimensions of the hatch are dependent on the size of the pump. However, organizations often use standardized hatches.

1.7 Niveaumeetbuis

A Niveaumeetbuis is a pipe for measuring the (ground) water level with a telemetric system. On a water pumping station, the instroomconstructie features two niveaumeetbuizen. One on both sides of the Kwelscherm.

1.8 Slibschot

A slibschot is a wall or plate positioned at the front of the instroombak that serves to retain sludge. It is used when the depth of the instroombak floor is grater that the bottom of the adjacent waterbody. The level of integration of the slibschot into the tool determined by the available time, as it is not mandatory to validate the tool’s concept.

1.9 Sponning

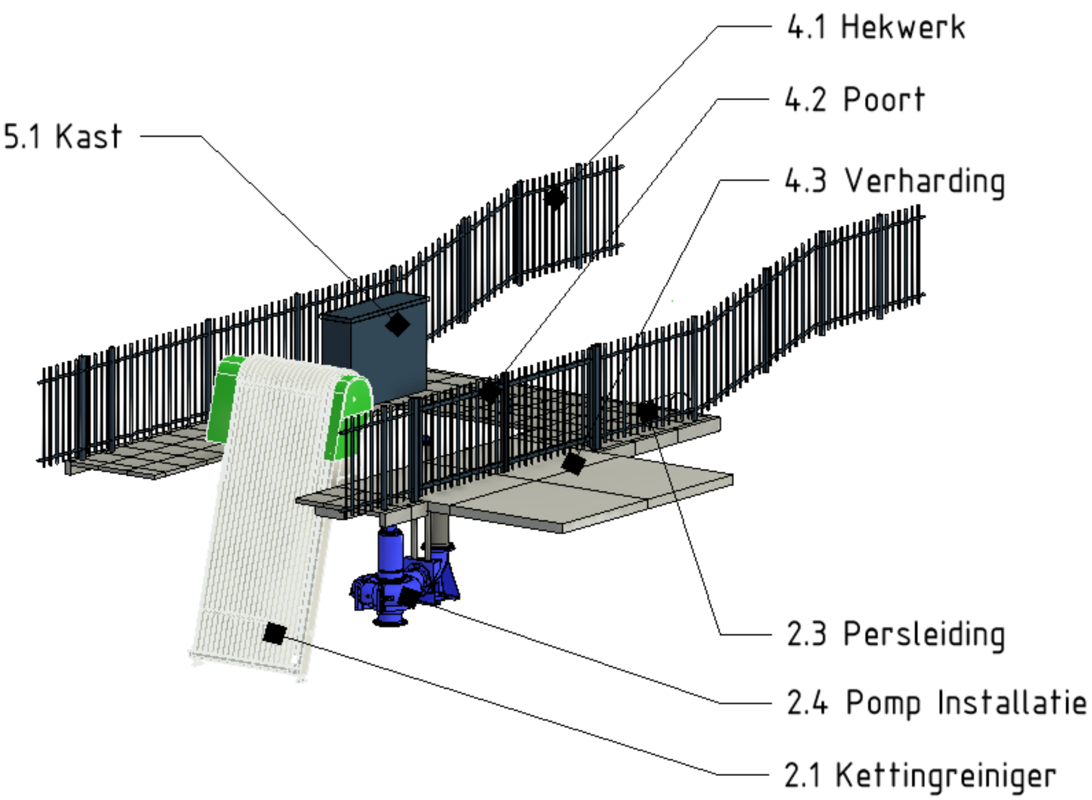
The sponning is a groove or joinery in which an object can be placed. In the context of a water pumping stations, a plate or beam can be placed in the sponning to prevent water from flowing into the instroombak. The sponning is formed during the casting process of the instroombak, at a standardized distance from “the Neus.” The dimensions of the sponning are often adjusted to fit standardized plate dimensions or are adapted to the dimensions of the mechanical equipment.

1.10 Vleugelwand

The vleugelwanden serve as retaining walls that support the ground. They are positioned in front of the structure and are placed on top of the Kwelscherm. These walls are made of concrete and can be placed either orthogonal or at an angle to the waterbody. The width of the vleugelwanden is determined by the width of the waterbody and the instroombak or uitstroombak.

2.0 Werktuigbouwkundige (WTB) installaties

The werktuigbouwkundige installaties (mechanical installations), refer to objects that are designed and operated through mechanical engineering principles. These installations consist of moving components or components that are primarily designed by mechanical engineers. The werktuigbouwkundige installaties consist of:



2.1 Krooshekreiniger(kettingreiniger)

A krooshekreiniger is the automated version of a krooshek (1.6). There are krooshekreiniger in all shapes and sizes, such as vingerreinigers and versions with an overhead crane. For this study, a vingerreiniger is being considered. Vingerreinigers are available in several standardized width sizes with varying height sizes. The angel of a krooshekreiniger is often 15 degrees. The height of the instroombak is decisive for the y distance for the krooshekreiniger. The krooshekreiniger is attached to the instroomdek and floor of the instroombak.

2.2 Ontluchting

The Ontluchting (air release system), is responsible for releasing air from the piping system to allow water to flow in. The placement of the ontluchting system is not aways fixed, but it is often located near the uitrstoomconstuctie.

2.3 Persleiding

The Persleiding refers to a pipe that is used to transport a medium or gas with the help of a pump. It connects the instroomconstructie to the uitrstoomconstuctie. At the instroomconstructie, the Persleiding is linked to the pump, specifically to the FFR connection pipe. Following the FFR connection, a multijoint is placed to connect pipes to various pipe sizes and materials. The multijoint is then attached to a pendelstuk, which allows for movement of the pipe due to diol or construction movements. At the uitstroomconstructie the Persleiding is connected to the uitstroombak, and a non-return valve(terugslagklep) is present ate the end. The diameter of the Persleiding is determined by the pump installation, capacity, and pipe length. The materials considered for the tool's development include HDPE, concrete, and Glass Fiber Reinforced Polymer (GVK).

2.4 Pompinstalatie

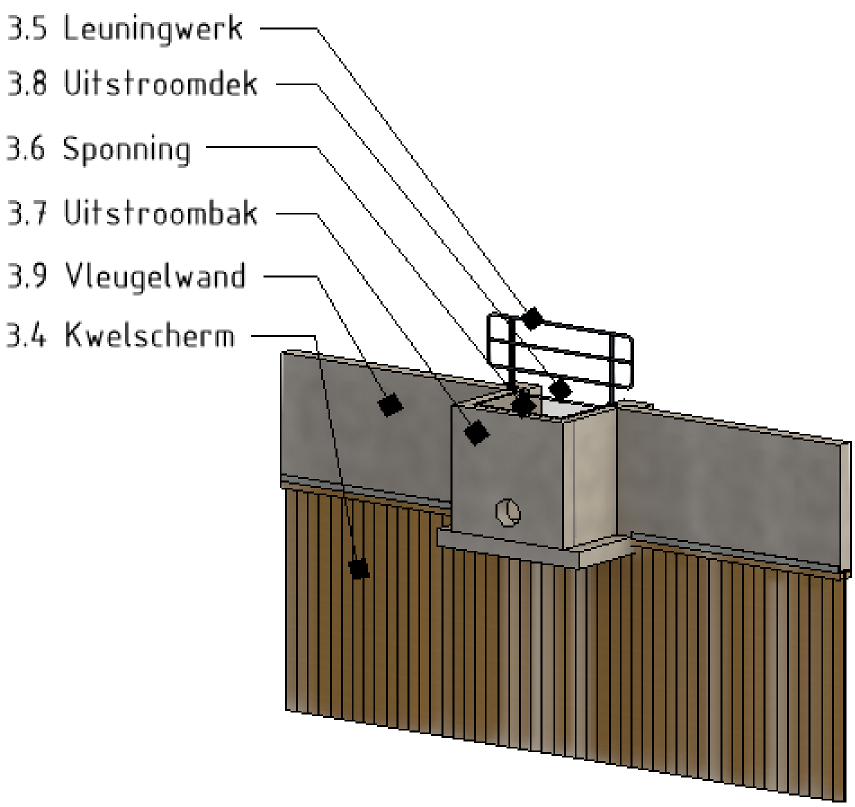
The pompinstalatie (pump installation), which is a crucial component of a water pumping station, is located in the instroombak. The size of the pump is crucial to the overall design of the water pumping station. The pump's size is determined by its capacity, and it varies depending on the supplier. The pump installation also includes the piping behind the pump ant the attachment rail. The pump's dimensions and parameters are illustrated in Figure 13. For this thesis research only three pumps are included in the parametrization, however the parametric model is developed for further expansion of the pump database.

2.5 Terugslagklep

The Terugslagklep, also known as non-return valve, is located at the end of the persleiding in the uitstroomconstructie. This valve is designed to allow the flow of water liquids, granyles, powders or gas in only one direction and prevent flow in the oposite direction. In water pumping stations, these valves are sourced from different manufactures and teir diameres depend on the dimensions and materials used for the persleiding.

3.0 Uitstroomconstructie

The uitstroomconstructie refers to the place of a water pumping station where the water leaves the system. The uitstroom constructie is often situated higher then the instroomconstructie. The uitstroomconstructie consists of the following elements:



3.1 Beschoeiing

Beschoeiing is connected to the water pumping station at the side of the waterbody and can be defined as a shore protection consisting of an orthogonal wall that safeguards the shore form erosion. The extent to which the Beschoeiing will be incorporated in the tool's development depends on the available time since Beschoeiing is not critical to validating the concept of the tool.

3.2 Bodembescherming

Beschoeiing is connected to the water pumping station at the side of the waterbody and can be defined as a shore protection consisting of an orthogonal wall that safeguards the shore form erosion. The extent to which the Beschoeiing will be incorporated in the tool's development depends on the available time since Beschoeiing is not critical to validating the concept of the tool.

3.3 Fundering

Fundering is the Dutch equivalent of foundation and can be described as a structure located beneath or at ground level that distributes forces to the underlying sturdy layers if soil. The fundering is located beneath the Instroombak and is determined by the dimensions of the Instroombak. For Wetterskip Fryslân, they often place new superstructures on existing foundations. To simplify the tool's development, four foundation piles are positioned beneath each of the supporting beams of the Instroombak and Uitstroombak. However, for further refinement, the placement of the foundation piles can be optimized based on structural calculations. The ground anchors connected to the Kwelscherm are part of the fundering. Their location and dimensions are not parameterized since they are only included for reference purposes.

3.4 Kwelscherm

The Kwelscherm is located beneath the instroombak, uitstroombak and vleugelwanden and serves as a vertical, impermeable structure that retains water flows. Various materials and techniques can be used for the construction of a Kwelscherm. Wetterskip Fryslân employs a pine Kwelscherm consisting of planks and two connecting beams for the water pumping stations in the designated range of water pumping stations. The width of the Kwelscherm is determined by the width of the retaining vleugelwanden.

3.5 Leuningwerk

The Leuningwerk is situated on the vleugelwand within the verharding and in between the hekwerk leuningwerk is situated that serves as support and prevents falls from heights in the waterbody. The width is dependent on the dimensions of the vleugelwanden.

3.6 Sponning

The sponning is a groove or joinery in which an object can be placed. In the context of a water pumping stations, a plate or beam can be placed in the sponning to prevent water from flowing into the uitstroombak. The sponning is formed during the casting process of the uitstroombak, at a standardized distance from end of the uitstroombak. The dimensions of the sponning are often adjusted to fit standardized plate dimensions or are adapted to the dimensions of the mechanical equipment.

3.7 Uitstroombak

The uitstroombak is designed to prevent soil erosion and is a sump that is connected to the persleiding. It contains th enon-retrn valve and groove. Standardized design choices within an organization often determine the dimensions of the uitstroombak. The height of the uitstroombak depends on the water and ground levels

3.8 Uitstroomdek

The uitstroomdek is a part of the construction which primary function is to cover the uitstroombak. The uitstroombak is often a roster or plate wich is removeable.

3.9 Vleugelwand

The vleugelwanden serve as retaining walls that support the ground. They are positioned in front of the structure and are placed on top of the Kwelscherm. These walls are made of concrete and can be placed either orthogonal or at an angle to the waterbody. The width of the vleugelwanden is determined by the width of the waterbody and the instroombak or uitstroombak.

4.0 Terrein

The term “terrein”in the context of water pumping stations refers to all the elements within the premises that do not directly affect the functioning of the station. The ellements of the terrein include:

4.1 Hekwerk

The Hekwerk also known as fencing, is composed of rails and poles that serce as a barrier to prevent unauthorized enty into the facility. In water pumping stations, the Hekwerk is located on both sides of the structure. Depending on the design, the hekwerk may surround the instroom and uitstroombak individually, or the entire structuer may be enclosed by the Hekwerk.

4.2 Poort

The Poort(gate), which is a component of the fence, is located at a point where vehicles can enter the facility, In the case of water pumping stations, the entrance is usually located on the opposite side of the niveaumeetbuizen. The dimensions of the poort are standardized for each organization, to allow dedicated vehicles to pass through.

4.3 Terreinverlichting

The Terreinverlichting(terrain lightning) is an essential component of water pumping station that procides illumination to the facility and particularly the area surrounding the instroombak. Typically, a lightning post is positioned behind the niveaumeetbuizen to ensure proper illumination of the instroombak.

4.4 Verharding

The Verharding(surface hardening) provides a stable ground for the movement of vehicles and peaople around the water pumping station. The hardening is customized based on the required space for personell and maintenance vehicles. Typically, behind the gate, there are four concrete slabs (2m x 2m). The area aroudn the instroom and uitstroom is covered with 50 x 50 floor tiles

5.0 Elektronische instalaties(E-Installaties)

The Elektronische instalaties (Electronic Instalations) encompasses all the systems linked to power and control for water pumping stations. In the design of the tool, all electronic installations are consolidated into one cabinet.

5.1 Kast

The Kast(cabinet), is an object in which the power supply and control systems are located. For the tool being developed , a standard cabinet will be used. The Kast is situated on top of the verharding with the back faced into the wind.