Automation of the design process in water streams

BSc-Thesis Civil Engineering

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PREFACE

Parametric design (PD) is one of the latest innovations after BIM in the design process of the building and infrastructure industry. To be able to investigate the possibilities of PD in the design process of water streams is something that got me exited immediately. Therefore I would like to thank Aad Engelen and Sander Verhagen for giving me the opportunity to start exploring and look for the answers in the big and wide fields of the parametric designing world.

Next to that I want to thank all colleagues at Sweco who have provided me with advice and guided me within the company. Especially Roel van den Elsen who has guided me technically throughout the whole project and all colleagues who were present during the expert elicitation.

Furthermore I want to thank Xianfei Yin for being my internal supervisor. Your comments and guidance have helped me a lot throughout this whole period and contributed significantly to my own development as a scientific writer.

If you are as exited at the end of reading this final report of my BSc Thesis Assignment 'Automation of the design process in water streams' as I was during the process of making it and want to know more about its contents then do not hesitate to contact me.

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SUMMARY

In this BSc Thesis Assignment the possibility of automating the design process in water streams is investigated. This is done using the method of parametric design. In parametric design relations are created between input variables and the desired output variables. By doing so, the outputted design changes when the input variables are changed. In this way the design process can be sped up due to the fact that the repetitive task of calculating the same formula every time with different input values is taken over by the parametric model. The models are created with the help of an example project called the Keutelbeek.

The research questions used in this thesis can be found below with the main research question on top in bold letters:

- **How can the design of water streams be automated?**
  - What existing knowledge is there already in practice and can be used to model water streams?
  - What features have to be in the Keutelbeek model in order to create a parametric template for other streams?
  - Which and in what form must the input and output be in order to be usable?
  - How can de designed model be validated and does the model pass the validation?

The automation of the design process is done using Dynamo which is an application within Civil 3D. With this application four different models are created which assist the designer when determining the route and design of the stream. The models indicate where it is impossible and possible to create a stream as well as where the stream does not fulfil to certain water requirements regarding discharge and flow velocity. Finally, the models help the designer with creating the stream bed lines at the correct location.

The created models are only a small step in the innovation process when considering the possibilities of parametric design. Therefore further research is recommended. By automating steps in the design process of water streams and possibly other constructions as well, the designer can focus on the creative, conceptual, and engineering aspects of the design process which increases design quality.

1. INTRODUCTION

The Keutelbeek is a stream which runs through Beek, Neerbeek and Geleen towards the Geleenbeek. The first part of the stream until Beek is an open, natural stream. The rest of the Keutelbeek travels further below the surface and is also used as a sewer. Due to the fact that flooding becomes more frequent, and the quality of the water is in poor condition (Waterschap Limburg, 2021), waterboard Limburg wishes to make the Keutelbeek visible again. In addition, the sewer system will be separated from the natural stream throughout Geleen. The new stream must comply with a few criteria which include that 1) the stream should be the lowest point in order to direct other streams to the Keutelbeek, 2) surface drainage should be possible, 3) the stream must have a natural appearance with enough space for greenery. A proposed new route for the Keutelbeek is shown in Figure 1. However, two options can be seen in the figure, it is decided by Sweco that the stream will travel through the Van Akenstraat.

FIGURE 1: PROPOSED ROUTE KEUTELBEEK (WATERSCHAP LIMBURG; GEMEENTE SITTARD-GELEEN; BUREAU VERBEEK, 2021)

The waterboard has asked Sweco to deliver a design for the stream through Geleen. Since numerous designs are possible within this case, the company would like to have an easy way to alter variables and check if a design is possible without having to renew the design manually. This is where the first idea of using parametric design in the design process of water streams appeared. PD is a method where the simplicity of altering variables and checking feasibility of designs is one of the key benefits (Van den Elsen, 2022). As the company only had little knowledge about this way of modelling, they sought information and explanation about this topic. This information is gained by using this project as a study opportunity. This project can be used as a template for similar projects in the future and thus implement parametric design wider into civil engineering.

In this project, an automated designing method of a water stream is proposed, in order to 1) save valuable time in the design process, 2) get a quick oversight of various design alternatives 3) serve as a framework for automating the design of water streams for other similar projects. Parametric design is a promising technique to achieve the objective, as this is a method in which the design does not need to be manually created, changed, and checked (Bergman, 2021). With the help of parametric design, the process of designing can be standardized, and after that, the creation of different designs can be automated by only giving new parameters as input.

The research is carried out at Sweco in Eindhoven in the technology department. This is done using the above mentioned project which includes the opening to the surface of the Keutelbeek stream in Geleen. The Keutelbeek project ran parallel with this research, so the use of parametric design could be investigated throughout this project. As this project is not finished yet, other similar projects are used for validating the method of PD in water streams. The research question for this project is: "How can the design of water streams be automated?"

In parametric design, a model is made which will adjust its output values if a certain input variable is changed. This is done using internal logic arguments. The basis of the process is that the model delivers an outcome based on scientific calculations rather than the ideas of the designer. Fu (2018) defined this as followed: "Parametric modelling is implemented through the design computer programming code such as a script to define the dimension and the shape of the model". Another view on parametric

modelling according to Woodbury (2010) is that it can be seen as a system of elements that are connected together through relationships and that evolve together, which resulted in the following statement by Woodbury (2010): "This system can therefore be seen as a series of mathematical equations made up of variables which, when fixed, give rise to project proposals". The designer will set the boundaries for the project using these series of mathematical equations and the model will generate a hierarchy of possible variables, which the designer then can use to explore various potential designs. According to Ji et al. (2013), the method of PD is increasingly used to create easily changeable models of infrastructure facilities. "In the planning of large infrastructure facilities ranging over several kilometres, such as tunnels or roads, new requirements on the underlying models have become evident." (Vilgertshofer & Borrmann, 2017)**.**

The final stadium of PD in water stream projects lays beyond the scope of this research. This desired final stadium is to be able to generate a design on the spot with live input from stakeholders. In this way a 3D impression can be generated immediately based on hard input such as dimensions, but also on soft input such as aesthetics. In order to get to the point of designing with this soft input, first a model which calculates through hard input must be created in order to have a large enough basis for a model using soft input (Van den Elsen, 2022). Therefore this research is focussed on modelling with this so-called hard input using the Keutelbeek project as an example project.

A variety of software applications which are designed to assist working with parametric design can be found ranging from the easy understandable Excel to the more complicated Python. Excel is the best software to use when creating simple parametric tools, but if the tools become more advanced the software has limited possibilities to process data and show another kind of visualisation (3D models, maps, etc.) (Bergman, 2021). Compared to Excel, Python is much easier when making advanced tools. On the contrary, it can be very intimidating to someone without programming experience (Bergman, 2021). Another possible way of designing the stream, besides Excel and Python, is to for example use the software of Autodesk. This company supplies various programs, such as Revit or Civil 3D, which support Dynamo, an application created in order to be able to design parametrically. Compared to Grasshopper (another software which supports parametric design), Dynamo has the advantage that it is a product of

Autodesk, which is commonly used at Sweco. As there was already a lot of knowledge present within the company about Civil 3D and some about Dynamo, the decision was made to use Dynamo as the main software in the project. Dynamo will be easier to understand and integrate into the current way of working by the employees at Sweco. Other advantages of Dynamo are that it gives the possibility to combine Excel and Python into the targeted model, so that the advantages of using these applications do not go to waste. In addition, its interface is easy to understand as can be seen in Figure 2, which makes the tool easier to be adopted within the company in later stages.

Dynamo uses input from the Civil 3D document such as points or lines or external input (for example from an Excel sheet) in the process. This process is built out of nodes which each represent an operation such as moving points or calculating lengths. Those nodes combined and linked generate the output which can be in all sorts of forms such as creating new or adjustment of already existing objects or layers. For more advanced programming the nodes can also be translated to code lines which can be helpful to keep the model structured.
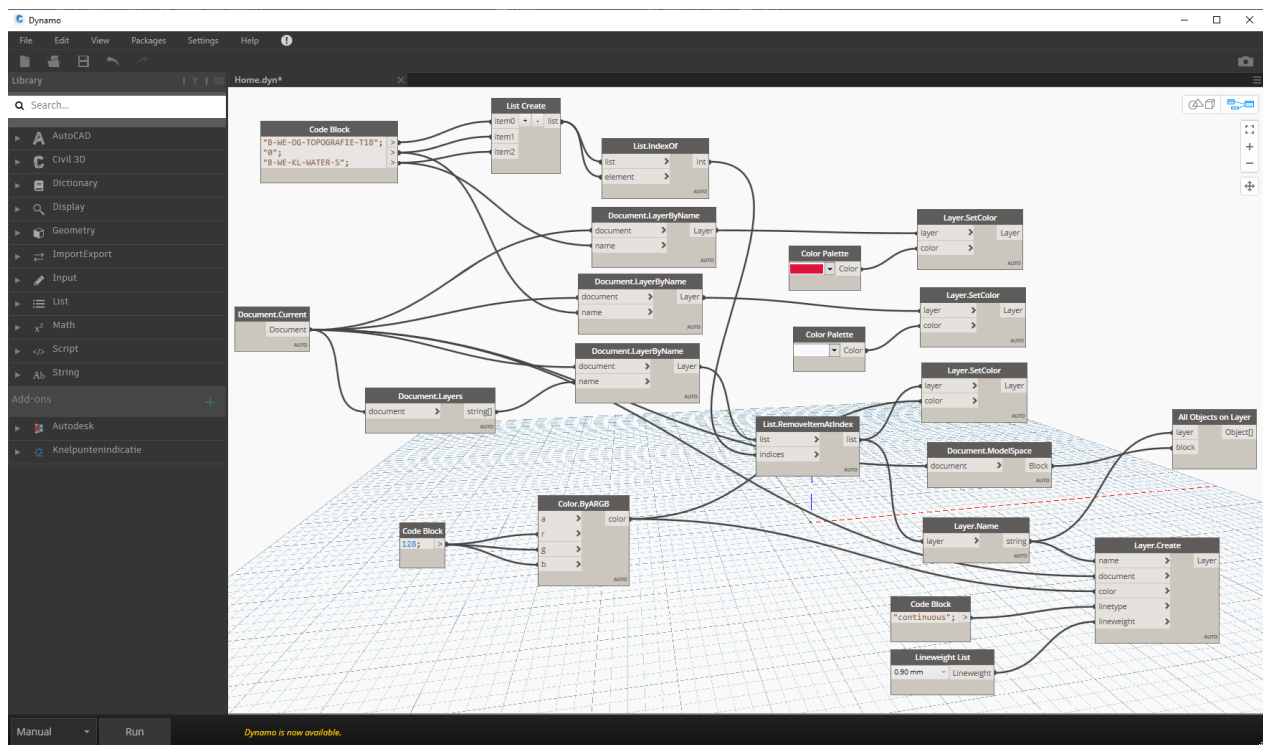
FIGURE 2: INTERFACE DYNAMO

The goal of the project was to propose a framework to automate the design process of water streams. This is done by using the parametric design process in the Keutelbeek project, which serves as benchmark for following projects with similar characteristics. The research focussed on the process of modelling with parametric design rather than focussing on the outcome of this one particular example, so that it is more suitable to be used in different projects. The research approached this problem with the help of scientific papers, by researching the existing software, and by investigating the knowledge of domain the experts at Sweco have regarding the use of parametric design software.

2. THEORETICAL FRAMEWORK

2.1 CHARACTERISTICS AND USE-CASES OF PARAMETRIC DESIGN

Parametric design can be used for many purposes, but it is mostly handy for fast switching between different types of designs and speeding up repetitive tasks. According to Oxman & Gu (2015) it can be described as a design methodology based on a digital scripting environment with the purpose of quickly altering design alternatives. Automation is desired when large numbers of design cycles come into play. Often, high flexibility and level of detail in an early design phase are desired. This can be achieved by a PD-based design process (Harding & Shepherd, 2017). Coding, such as sweeps, extrusions, lofts or Boolean operations, can create a 3D object out of a 2D sketch, which enhances this flexibility and level of detail.

There are a lot of benefits regarding the use of the parametric design process. The most important one is that this way of working can save a lot of time by shortening and simplification of the design process, which in the end results in less costs (Holzer et al. 2007). Another more indirect benefit according to Holzer et al. (2007), regards the visualisation that often comes with PD. This could clarify design results and its aspects. Vilgertshofer & Borrmann (2017) concluded that required parametric dependencies which are defined manually, can result in a very complex, time-consuming, and error-prone task, which could benefit from automation. By taking away this likelihood of human error, the quality of the design increases. Vilgertshofer & Borrmann (2017) also stated that by increasing automation of repetitive modelling operations, the designers can use their new available time to focus on the creative, conceptual, and engineering aspects of the design process. Other benefits stated by Behage et al. (2021) are that PD improves decision-making, collaboration, scalability, and easier storage of design knowledge.

The downside of using parametric design is that not a lot is known about the topic yet. However, the concept is quite clear overall, ways of implementing it into the design process is often still a challenge. Due to the interoperability, the structure of the model can become very large and thus harder to operate. An important factor in this is that the set of rules which needs to be created in order to reach the desired modelling outcome can become very large before the method can be productively used by designers

(Vilgertshofer & Borrmann, 2017). Designers still have to get to know the software in order to easily apply models to the designs which costs time and consequently money. According to Vilgertshofer & Borrmann (2017), currently available BIM modelers do not support working with defining parametric dependencies which results in that most cases with parametric functionalities are brought down to rather simple pre-defined dependencies. Another threshold that needs to be overcome according to Aranda-Mena et al. (2009) and Warner & Wäger (2019) is that there should be a cultural change in attitude before parametric designing can be fully integrated into the standard design process.

The development of PD is mainly caused by the development of the digital world. Stals et al. (2021) explained this by looking at the renewed conceptual framework and theoretical foundation which were required due to this development of the digital world. This was required due to the fact that digital design and its increasingly impact on design and production practices needed a reassessment of design theories, representation of workflows and models. This was emphasized by Oxman (2006) who proposed that the tools used when designing have a significant impact on the design process itself.

There are many cases where parametric design is applicable. The use cases range from a model which minimizes embodied carbon in reinforced concrete flat slabs by parametrically varying the slab thickness, grade of concrete, column spacing, column size, and reinforcement details (Jayasinghe et al., 2022), to even creating a simulation model of the human mandible which will be used as the basis for the future optimization process of individual jawbone implants (Wieja, et al., 2022). Some examples of remarkable buildings designed parametrically can be seen in Figure 3.

Museo Soumaya **Walt Disney Concert Hall** **Canton Tower**

FIGURE 3: EXAMPLES OF BUILDINGS DESIGNED PARAMETRICALLY (COOREY, 2020)

According to Girardet & Boton (2021), infrastructure projects, such as bridge designs, are increasingly designed with technologies associated with BIM. By exposing the technical constraints in infrastructure projects, Ait-Lamallam et al. (2019) was able to analyse the possibility of integrating parametric design into road projects. They concluded that interactions with standards often constitute a barrier to the use of parametric models. As stated by Girardet & Boton (2021), literature available regarding parametric modelling remains extremely sparse, which causes another barrier when trying to begin using parametric design.

A project that has similarities to the current research is that of Girardet & Boton (2021). In their study the objective is to develop a parametric file that allows the user to create all types of bridges from a single parametric file. Which sums up roughly the same idea for this project except for the use case. Another example of a slightly resembling project is that of Naize et al. (2019) which is about pseudo-natural water scenes of gardens. In the project parameters are standardized in a way that if the input is changed, the software automatically creates the optimal design scheme for the pseudo-natural dynamic water scenes in the garden view.

2.2 VALIDATION AND QUALITY ASSESSMENT

One method which is used in order to validate and check for usability of the model is the NUSAP-method which can be explained by the five terms it consists out of namely: Numeral, Unit, Spread, Assessment, and Pedigree. It can be described as a notational system which copes with the uncertainties in science with special attention to the management and communicational side. The method was introduced in 1990 by Silvio Funtowicz and Jerome Ravetz in their book 'Uncertainty and Quality in Science for Policy' where they explain the main use of NUSAP which is to improve the process for political decisions due to the fact that "facts are uncertain, values in dispute, stakes high, and decisions urgent" (Funtowicz & Ravetz, 1990).

The first three out of the five categories can be seen as the traditional part where 'Numeral' is most of the time an ordinary number or quantity with a 'Unit', for example meter or grams. 'Spread' describes an assessment of the error in the value of the 'Numeral' of the output variable(s). According to Berner & Flage (2016), 'Spread' can be

seen as a quantitative representation of uncertainty which relies on the statistical methods to create ranges of inexactness/variability of the quantity/information in the 'Numeral' qualifier.

The last two factors in NUSAP, 'Assessment' and 'Pedigree', are used to show qualitative judgement of the information and complete the evaluation of information in a qualitative manner. According to (Funtowicz & Ravetz, 1990) 'Assessment' is a flexible category, meaning that the interpretation and associated notations can vary, whereas 'Pedigree' is added to reveal uncertainties that occur at a deeper level than the ones in the other categories. It shows the evaluative account when considering the production process of the quantitative information. This is done by using the Pedigree matrix which will be provided later in 4.3 Process: Validation. How the NUSAP method is used in this project is shown in the same section.

3. PROBLEM STATEMENT AND RESEARCH OBJECTIVE

3.1 PROBLEM STATEMENT

Before this thesis, there was not a developed fast way of designing water streams automatically. All parts were designed by hand, which resulted in a lot of repetitive work. Methods to run a model that calculates if the waterway passes all requirements were missing as well as methods that can adapt the position of the waterway in order to comply with the requirements. The problem was that there was not enough knowledge about how to generate such models which can design water streams.

3.2 RESEARCH GAP

Parametric design is more and more implemented into the design process (Van den Elsen, 2022). On the contrary few documents could be found which specify parametric design and even fewer which specify parametric design in infrastructure. As stated earlier there do exist infrastructure projects however which use parametric design in the process, such as the bridge design. As can be concluded from section 2. Theoretical framework, not a lot of projects could be found which use parametric design in water stream projects and none could be found which fully cover the whole process. Therefore, this research potentially fills parts of this research gap.

The research gap helped with focussing on what was still out in the world to discover regarding parametric designing. Vilgertshofer & Borrmann (2017) stated: "parametric design is generic and applicable to a wide field of modelling tasks that either require consistency preservation or the application of complex parametric and procedural modelling operations". This gave hope for a positive outcome out of this research. In Vilgertshofer's and Borrmann's paper, parametric design is applied to a shield-tunnel scenario. With this they have proved that it is applicable in this specific context. They also argued that they are not ready to prove that their developed theory is applicable in a generic manner, but in my opinion, the shield tunnel scenario had multiple aspects similar to the Keutelbeek project, so this theory could be used to some extend in this research.

3.3 RESEARCH QUESTIONS

In order to solve the problem stated in 3.1 Problem Statement, several research questions were defined which are stated below. In the bold letters the main research question can be seen. This research question also contains sub-questions which are there to specify the main research question.

- **How can the design of water streams be automated?**
    - What existing knowledge is there already in practice and can be used to model water streams?
    - What features have to be in the Keutelbeek model in order to create a parametric template for other streams?
    - Which and in what form must the input and output be in order to be usable?
    - How can the designed model be validated and does the model pass the validation?

3.4 RESEARCH OBJECTIVE

The objective of this research is to automize the designing of a water stream. The models used in the Keutelbeek project should function as a template for similar projects. The models should be able to tell the user if the bed of the stream is at the correct height compared to the upper surface. Furthermore, models which adjust the route of the stream must be created. These models must take into account factors such as available adjustable space and the width of the newly designed stream. With the minimal adjustment, these models must be able to work for different types of streams. What is not included in this research is the creation of 2D designs of the stream, as this is not of importance for automation, however, the 2D designs will be used in the models to create a 3D design. Next to designing the model, it should also be validated.

4. RESEARCH METHODS

This section elaborates more on how the project is executed. This was used as guidance throughout the project. The research methods used are displayed in several workflows. Items in the workflows are provided in different shapes and colours. The definition of these shapes and colour can be seen in Figure 4.
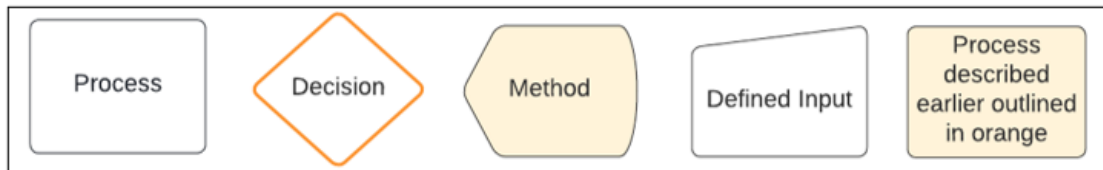

FIGURE 4: SHAPES AND COLOURS USED IN WORKFLOWS

In Figure 5, a workflow of the project process is presented. The figure is divided into three sections: input, process, and output. Each section is divided into steps which is elaborated in more detail in the next part below the figure with special attention to 'Dynamo model Keutelbeek', as this part is the core of the project. 'Dynamo model Keutelbeek' has its own separate workflows to visualize further what steps are taken whilst creating the model in Dynamo. Furthermore is the process section that is divided into two parts which each describes the process of creating and validating the model.
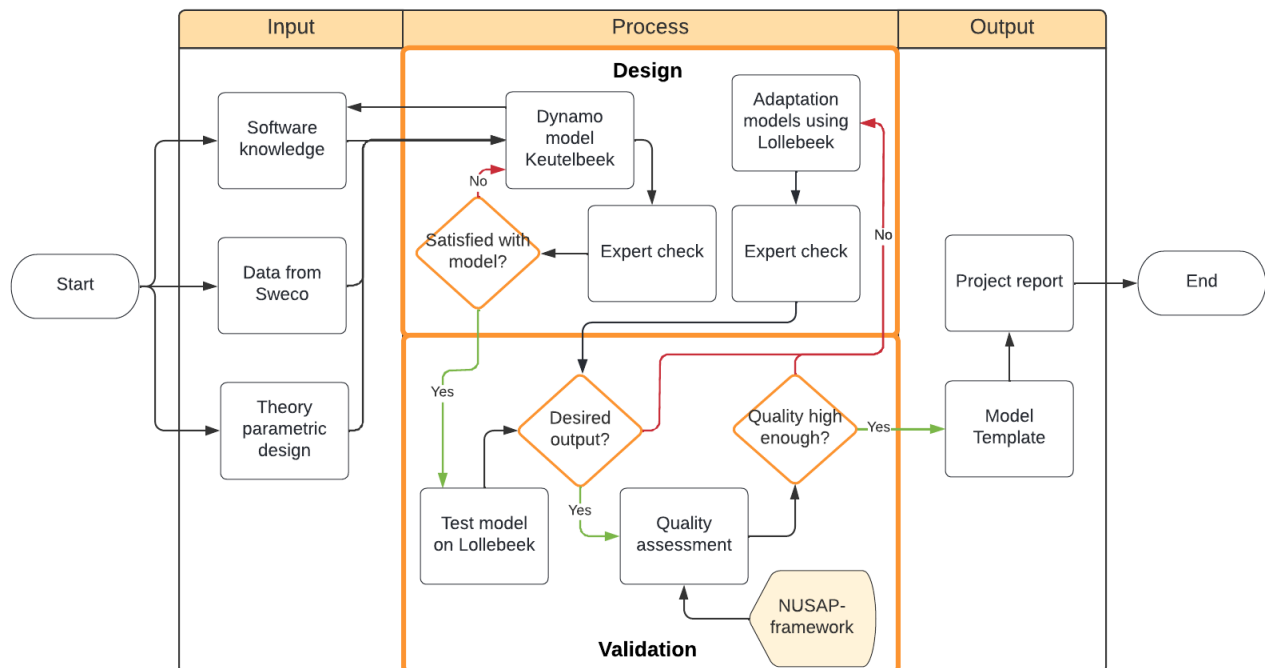

FIGURE 5: FLOWCHART COMPLETE RESEARCH PROCESS

4.1 INPUT

There are several methods and programs which are designed to automate the designing of construction and infrastructure. As discussed in 1. Introduction, the software which is used in this project is Dynamo. This is user-friendly software, which is interconnected with Revit and Civil 3D. Currently, this method is used in another branch of Sweco for designing highways and the goal is to use it in Eindhoven for designing water streams as well. The knowledge from the colleagues in De Bilt is therefore used to complete this project. The expert from the branch in De Bilt advised to start with small parts of the stream and expand the model in steps when the modelling is successful. This advice is followed throughout the whole project. While the goal was to model the complete Keutelbeek, the modelling of smaller parts that are reliable and can contribute to a more efficient design process was of greater importance.

From the literature collected before the start of the research could be concluded that there was enough basis to start with this research. Not only that knowledge is used as input for the model, but a lot of other sources are used to be able to create the model in Dynamo, such as data and software knowledge. Of course, by using the software the program becomes more known, which in the end helped as well with the handiness in modelling with Dynamo. This is considered to be the 'Software knowledge' which can be seen in the input section in Figure 5. A Big part of this software knowledge is the ability to use Python and Excel within the dynamo models. Excel is mostly used in the designed models as an easy template where the input parameters can be listed. The Dynamo model in its turn pulls those data out of the Excel file and translates this to usable input. As Dynamo is not designed in a way that it can handle loops, Python is a real benefit to use inside the Dynamo model. One additional benefit of using the Python nodes is that the Dynamo model becomes more structured and uncluttered.

Another input step which can be found in the same figure is the 'Data from Sweco' which consists out of all input parameters the models use in order to get to a design. All input parameters meters will be discussed per model in the next sections. Other data which is provided by Sweco is context and content about the Keutelbeek project and later in the process about the Lollebeek project in the form of presentation slides, documentation, and the help of experts. When looking at the process of

designing a water stream, the design passes through multiple teams within Sweco, especially the water and technology department. This is the reason why experts from those departments were interviewed on what they believed to be the advantage of parametric design in the design process of water streams and in what way it should be implemented. The combination of those interviews became the basis for the model. The 'Theory parametric design' step was another basis for beginning to model the Keutelbeek. The parts which have greater influence on the end result were known by examining the theory. This knowledge was used during the design process in order to be able to focus on those parts.

4.2 PROCESS: DESIGN

During the process of creating the model there was an 'Expert check' every time significant progress was made. In this step an expert at Sweco was asked in a casual conversation if the model complies with the requirements set at that stage of the research. This step was an extra check in order to guide this research in the right direction. At the moment the expert was satisfied with the model, the validation phase could begin which is described in 4.3 . At the moment the expert was not satisfied with the model, adjustments were made and the design loop was started again. If the design did not give the desired output in the validation phase, the model was adjusted until it did give the desired output. This adjustment of the model was done using the Lollebeek as this is the stream which is used in the validation phase. After this adjustment the model passes the 'Expert check' again. After the model was validated and the quality was accepted a 'Model Template' was created in order to be able to design other water streams with the model.

4.2.1 MODEL CREATION

In the process of modelling the stream, the working file became too big which meant 1) long waiting times for the model to run, 2) unclear structure in the model and thus 3) a slower and harder process of designing. This is the reason why the model was split into three different models at first, with later in the process an additional fourth. By doing so it could be avoided that the models would become significantly big quickly which would mean a lot of computer capacity is demanded. Another consequence that could be avoided is that the structure becomes very unclear due to the fact many code blocks will

be implemented into the model (Van den Elsen, 2022). The models are divided into the models described in the workflows below. For each workflow an additional description is provided. As discussed earlier all phases were executed in small steps in order to keep it uncluttered. For example, first a few data points were inserted into the model which gradually increased while the project continued. An overview of what the models produce as output can be found in 5.1 Model creation.

4.2.1.1 CIRCLES AROUND OBSTACLES

The first model is designed as a tool which helps the designer with setting up the first sketched line of the stream. The model creates circles around obstacles with a given forbidden range as radius. In this way the designer can easily see which route is most likely to be successful when considering available space. The model has as variable the option to add or delete the circles in the Civil 3D file. The delete function is built into the model for the purpose of cleaning the Civil 3D document of unnecessary parts of the drawing at the end stage of designing. The processes within the model can be seen in the workflow in Figure 6.
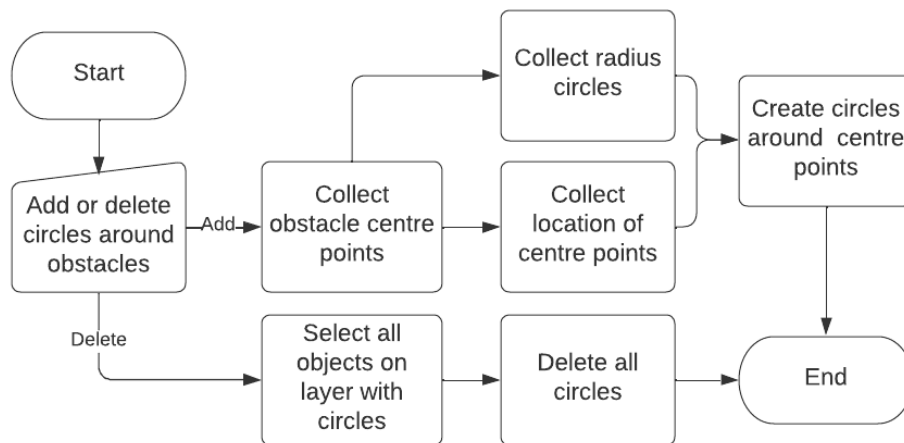

FIGURE 6: WORKFLOW "CIRCLES AROUND OBSTACLES"

4.2.1.2 MOVE STREAM IF OBSTACLE IS CROSSED

The next model is the largest model created within this project. The model checks for a given points per meter of the stream line if the stream comes too close to an obstacle. If any points are too close to the obstacles the model automatically moves those points to the correct distance from the obstacle. This moved distance is the amount of overlap the stream has with the obstacle. If those new points still come too close to an obstacle, for

example due to the fact that it is moved towards a different obstacle, the model will generate a red line at that location as indication to the designer that it is not possible to create a stream at that location with the given profile. The designer must come up with a different solution manually such as changing the route of the stream or placing a culvert (tunnel) at the location of the red line.

In Figure 7 the input parameters can be found on the top-left. As discussed earlier, one of the inputs is the amount of points the model calculates per meter of sketched stream. The higher this number the more precise the design is, but also the longer it takes to run the model. The expert in Dynamo from the branch in De Bilt advised to use 1 point per meter as a start. The next input is the layer name on which the stream middle line is drawn in Civil 3D. It is important that only the lines which need to be modelled are on that specific layer to avoid unnecessary processing. Next to the layer name, the properties of the stream are input for the model as well. For this an Excel template was made which can be seen in Table 1. The light coloured cells are calculated by predefined arguments. The white cells must be filled in manually.

TABLE 1: EXCEL TEMPLATE OF PROPERTIES FOR THE STREAM (EXAMPLE NUMBERS)

Course	Δh (start course): Streambed-Surface	Slope (m/km)	Streambed width	Slope left (width per meter height)	Slope right (width per meter height)	Length	Streambed height start course	Streambed height end course	Surface height start course
2	0.8	0.3	4	5	2	401.70	21.7	21.57949	22.5
3	2.12051	0.3	4	2	5	330.79	21.57949	21.480253	23.7
4	1.339747	0.3	4	2	5	579.35	21.480253	21.306448	22.82
5	0.983552	0.3	4	2	5	580.43	21.306448	21.132319	22.29

The last input for the model is described as "Model Circle around obstacles". This input uses the same process as described in the previous model when adding the circles.

The process of determining if the proposed stream fits begins with calculating the height, and consequently the width of the stream. This can be seen in Figure 7 in the orange square titled "Width and height calculation". The calculation is done using the following formula:

$$Width_{total} = Width_{bed} + \Delta h \cdot (Slope_{left} + Slope_{right}).$$

In addition to this the width on both sides of the middle line is calculated separately to tell how much the middle line must be moved. The next part needed is the direction the

new point needs to head. This is described in the orange square titled "Directions new points move in". How this direction is defined can be seen in Appendix A. Together with the created points on the middle line, the new points on the outer lines of the stream can be created. From these points the distance to the circles around the obstacles is calculated whereafter can be checked if this distance is large enough. If this distance is not large enough the points on the middle line are displaced in the direction away from the obstacle with the minimal distance needed in order to not cross the obstacle anymore. As described earlier a red line is generated if the new points are moved too close to another obstacle. From the new created middle line the designer can create a new smooth middle line which can then be checked again. This loop continues until the new middle line does not differ from the sketched middle line.
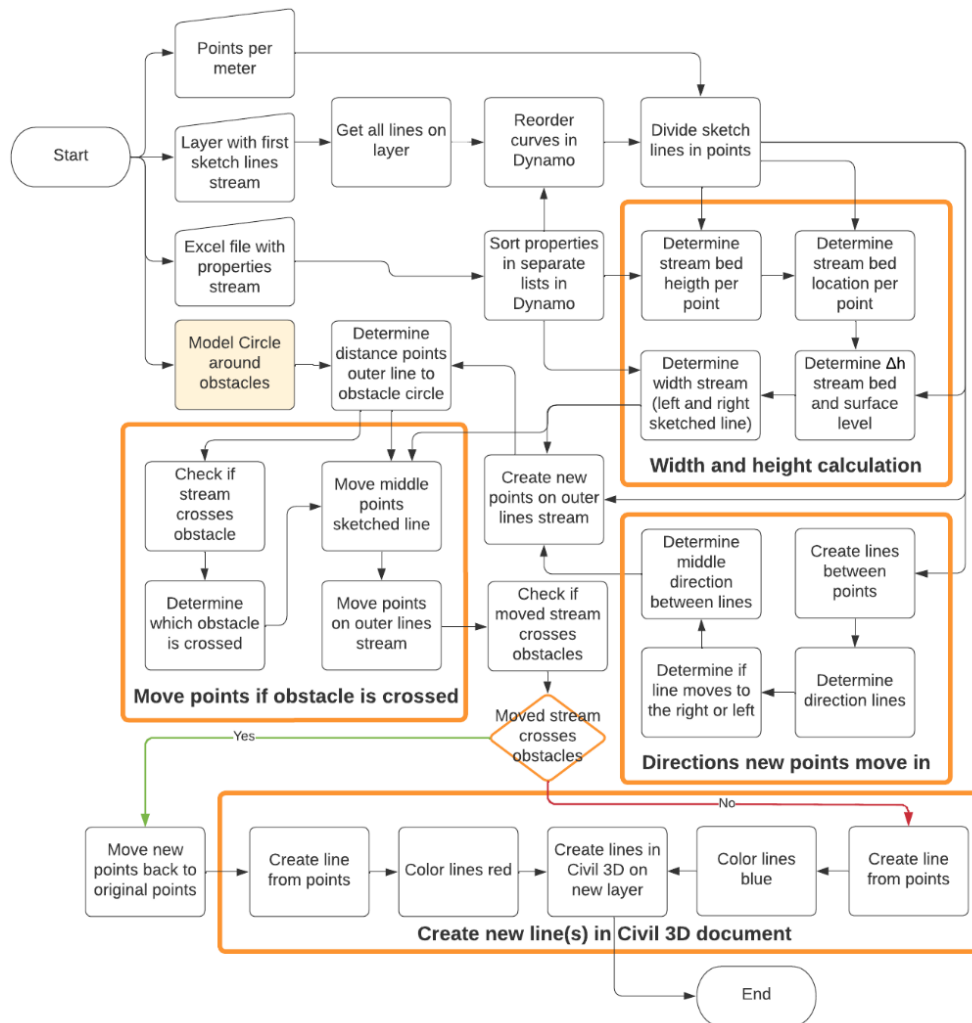

FIGURE 7: WORKFLOW "MOVE STREAM IF OBSTACLE IS CROSSED"

4.2.1.3 CHECK WATER PROPERTIES FOR THE STREAM

To get a quick indication if the new stream, which is created using the previous model, complies to the water properties calculated by the water department, a model is added to the design process which calculates the discharges and flow velocities at a given amount of points per meter stream. The desired discharge and flow velocity has a given range which the model uses in order to check for failures in the design. These ranges are input to the model together with a given Strickler coefficient and the orange square in Figure 8 called "Setup points and list properties" as explained earlier in 4.2.1.2 Move stream if obstacle is crossed. With the "Width and height calculation" and the Strickler coefficient, the Strickler formula can be solved. The formula and its components can be seen below. The discharge can be calculated by multiplying the flow velocity with the area at that point.

$$Strickler\ formula:\ u = k_{st} \cdot S^{1/2} \cdot R_h{}^{2/3}$$

$$R_h = \frac{Area}{P}$$

$$P = W_{bed} + \Delta h / (\sin{(\tan^{-1}(S_L))} + \sin{(\tan^{-1}(S_R))})$$

Where: $u = Flow\ velocity$ $P = Wetted\ perimeter$

$k_{st} = Strickler\ coefficient$ $W_{bed} = Width\ stream\ bed$

$S = Slope\ (m/km)$ $\Delta h = Height\ difference\ surface - stream\ bed$

$R_h = Hydraulic\ radius$ $S_{L/R} = Slope\ Left/Right\ (width\ per\ meter\ height)$

The model then creates a list of points which have water properties which lay out of the given range. These points are connected by lines and put on a separate layer in the Civil 3D file with a specific colour:

TABLE 2: LAYER NAME AND COLOUR

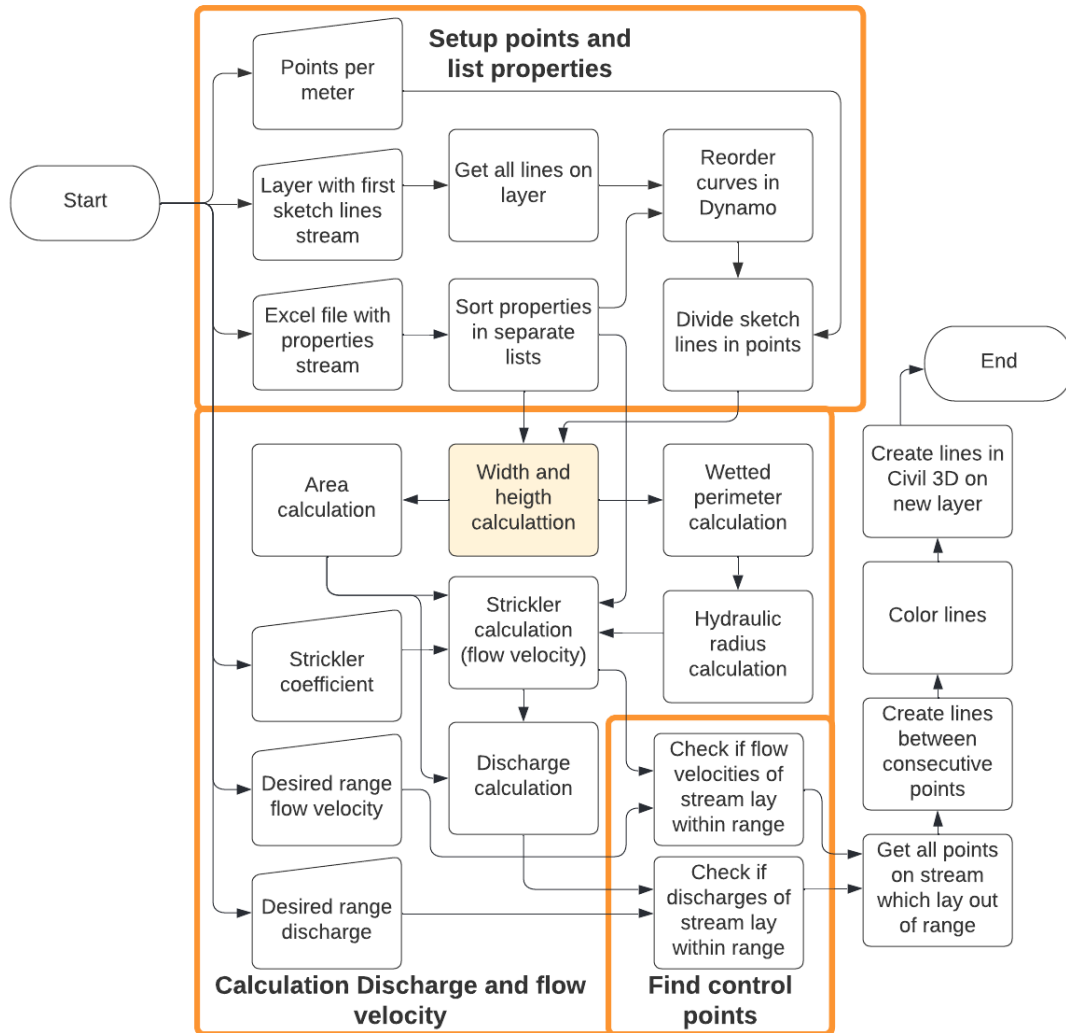| Layer	Colour
Below minimal flow velocity	Orange
Above maximal flow velocity	Yellow
Below minimal discharge	Pink
Above maximal discharge	Light green

4.2.1.4 CREATE STREAM BED LINES

If the model passes all checks of the previous models the drawing of the final design can begin. This is done by using the stream bed lines from which lines can be drawn towards the surface level. As it is not convenient to use the full surface within the process of running the Dynamo models, the final slopes from the stream bed to the actual surface must be drawn in Civil 3D. This easily be done using the grading tool. The creation of the stream bed lines which can be seen in the workflow Figure 9 begins with the previously described "Setup points and list properties". From there the stream bed points can be calculated using the x-y coordinates of the middle line. The points on the outer lines of the stream bed can be calculated using the same method as in 4.2.1.2 Move stream if obstacle is crossed called "Direction new points move in". As it is possible that

one of those points still lays too close to the middle line, a last check is executed. In this check all points which lay too close to the middle line are deleted. The last step is to create a line between the remaining points and put this on a new layer in the Civil 3D document.
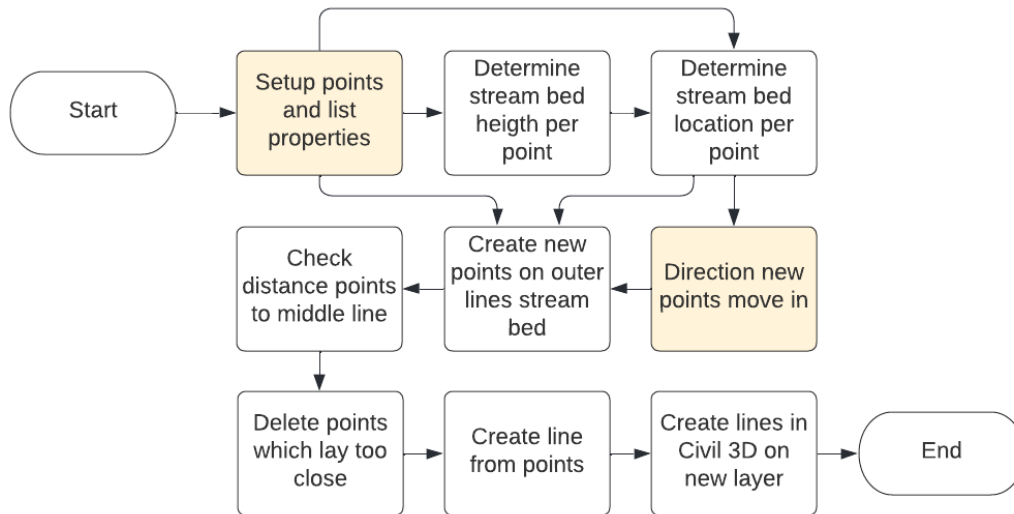
4.3 PROCESS: VALIDATION

The validation of the model is done using the design of the Lollebeek which the designers at Sweco created using the current way of working. The Lollebeek is chosen for the validation for the simple reason that the design of the Keutelbeek is not finished yet. This means no comparison can be made between the design made by the models and the design made in the old-fashioned way. The Lollebeek has similar characteristics to the Keutelbeek which makes it a valid stream for validation of the models. Another simple method which can used for validation is by measuring the output lines the models give. If the output lines have the correct desired dimensions defined by the input values, it can be said with more certainty that the models are working correctly.

Another important part of designing a model is to test the quality and check if the model is going to be used by the designers. If the model is not going to be used, because it is too complicated or not useful, the decision has to be made if further investigation or adaptation of the model is desired or if the model has reached its end. In order to find out if the model is useful in the design of the streams, multiple designers and experts at Sweco are be given the opportunity to have a look inside the model and

talk about their experience, expectation and what they would like to see differently. In Figure 5 this can be seen as the 'Quality assessment'. This was done during the expert elicitation which is part of the NUSAP framework. The main purpose of using the NUSAP framework is to reveal underlying flaws and for the sake of validating the method of PD. By applying the NUSAP framework, the method can be checked for inconsistencies. This is done by following the five steps of the framework which are finding all values for Numeral, Unit, and Spread followed by the Assessment, and creation of the Pedigree matrix. All input and output variables are checked and assessed. In order to create multiple point of views on the variables, the NUSAP framework is executed during an expert elicitation. The expert elicitation consists out of a discussion with the experts on the categories provided in Figure 10.

Code	Proxy	Empirical	Theoretical basis	Method	Validation
4	Exact measure	Large sample direct mmts	Well established theory	Best available practice	Compared with indep. mmts of same variable
3	Good fit or measure	Small sample direct mmts	Accepted theory partial in nature	Reliable method commonly accepted	Compared with indep. mmts of closely related variable
2	Well correlated	Modeled/ derived data	Partial theory limited consensus on reliability	Acceptable method limited consensus on reliability	Compared with mmts not independent
1	Weak correlation	Educated guesses / rule of thumb est	Preliminary theory	Preliminary methods unknown reliability	Weak / indirect validation

FIGURE 10: PEDIGREE MATRIX (KROL, 2022)

At the expert elicitation, the experts were asked about their opinion of the different categories in the pedigree matrix starting with proxy. Here the question was if the output variable gave a good representation of what the model user wants to know. This was answered in the range of 0 to 4, where 0 means not clearly related to 4 which means exact measure.

The next category on the list is empirical. In this section was determined how large the basis sample is. This was described from crude speculation to large sample and direct measurements.

The theory behind the model is of great importance which is the reason why this is the next category which was valued. Here was looked at the reliability and if the theory is accepted generally. This was valued in the range from crude speculation to well established theory.

To answer the question if the used model is the best available practice, the section method is added to the pedigree matrix. In this section, the used model was compared to alternatives, such as the current way of designing water streams, and was valued on how accepted the method is in general. Reliability of the method is another important factor in this. The category method was valued in the range from no discernible rigour to best available practice.

Last but definitely not least in the pedigree matrix is the validation. In this section the outcome variables were tested on the fact if they can be compared to measured data. If this is not the case, there will always be an uncertainty if the modelled data is a good representation of reality. The range in which this category was valued is from no validation at all to can be compared to independent measurements of the same variable.

5. RESULTS

5.1 MODEL CREATION

The output of the different models can be seen in this section. The first few figures are the results of the models when designing in the Keutelbeek area. These results are the intermediate results due to the fact that the model was adjusted after experimenting in the validation period. As those adjustments were immediately tested on the Lollebeek, those output lines of the Lollebeek project give the most complete and clear results. Therefore the final results are shown below the intermediate results using the Lollebeek. An overview of how the different models look in Dynamo software can be seen in Appendix B. This overview is provided in order to give an impression of the models. As the models are very large it is not possible to show what each separate node does. In the figures purple (representing input) and green (representing processes) boxes can be seen. Those boxes are represented in the workflows of 4.2.1 Model creation.

In Figure 11 the first intermediate result can be seen. The model used on this part of a fictional (due to the fact that the design is not determined yet) new Keutelbeek generates a full profile across the complete stream. On top of that it marks obstacles with the forbidden construction radius as well as moving the stream if it is drawn too close to an obstacle.

FIGURE 11: RESULT MODEL BEFORE SPLITTING UP INTO MULTIPLE MODELS

In Figure 12 results can be seen of the four different models on the Keutelbeek which resulted from the singular model which was used to create the design of Figure 11. From this point the models were further tested and validated using the Lollebeek. The functions of the different types of lines will be further explained in the sections below.
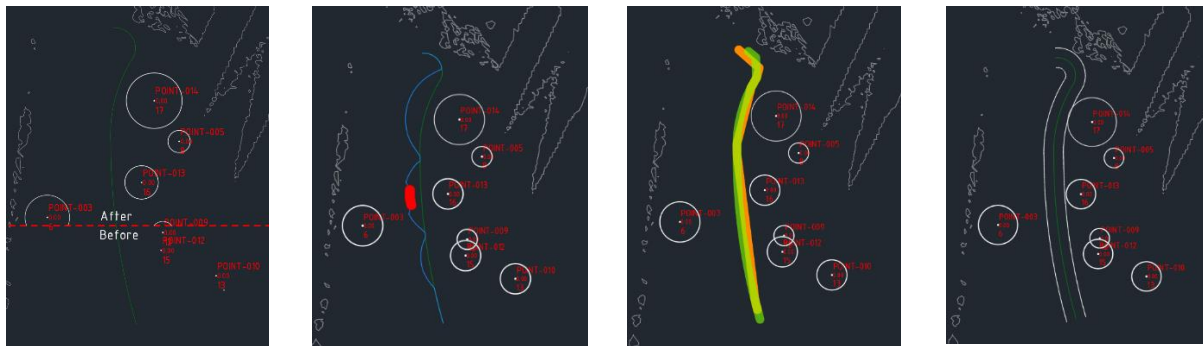
| (A) | (B) | (C) | (D) |

FIGURE 12. INTERMEDIATE RESULTS KEUTELBEEK: (A) CIRCLES AROUND OBSTACLES; (B) MOVE STREAM IF OBSTACLE IS CROSSED; (C) CHECK WATER PROPERTIES FOR THE STREAM; (D) CREATE STREAM BED LINES

The models can be activated using the Dynamo player in the manage tab in the Civil 3D document as can be seen in Figure 13. When opening the player, the models can be seen and executed using the play button. If input values need to be changed this can also be done using the Dynamo player. By using the Dynamo player the designer does not have to open the full script first. This has the advantage that the designer does not need to know how Dynamo itself works in order to be able to use it.
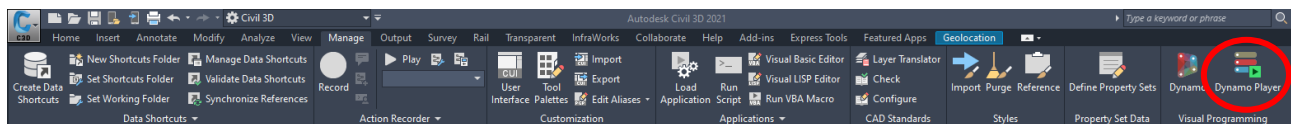

FIGURE 13: DYNAMO PLAYER BUTTON

5.1.1 CIRCLES AROUND OBSTACLES

As can be seen in Figure 14 the model creates the circles exactly around the obstacle. In the figures an example of multiple trees is given where one tree is drawn completely. By setting the coverage of the branches as forbidden area for the stream, the circle is generated at the end of the branches. The circle can now be used as guidance for the designer. This model was not adjusted anymore after the validation phase.
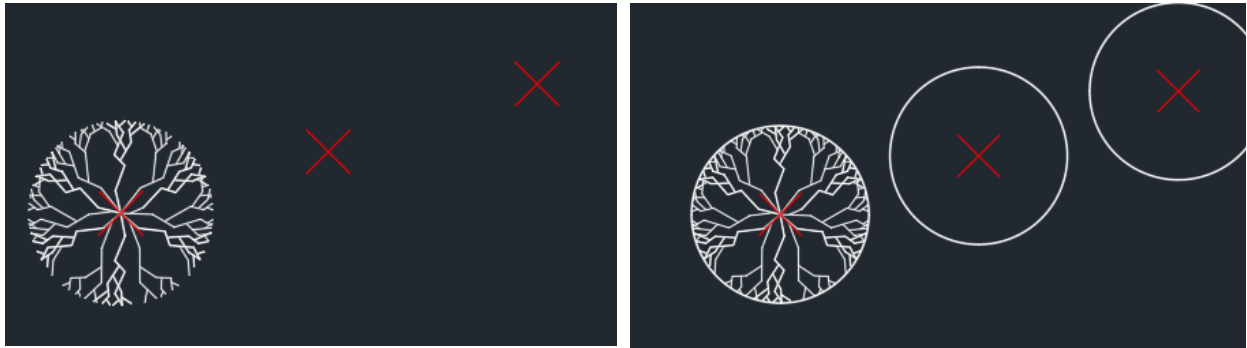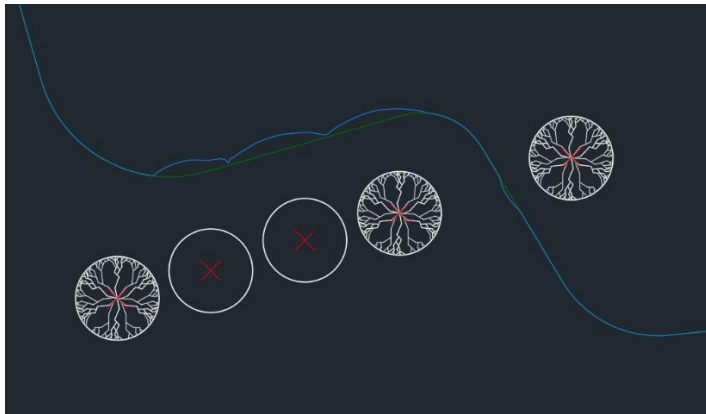

(A)   (B)

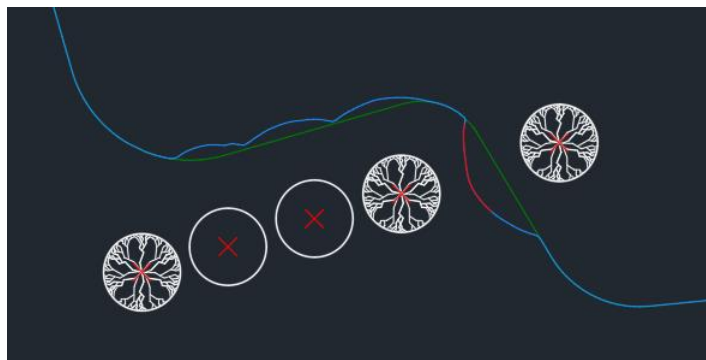**FIGURE 14. OBSTACLE POINTS: (A) WITHOUT CIRCLES; (B) WITH CIRCLES**

5.1.2 MOVE STREAM IF OBSTACLE IS CROSSED

(A)

(B)

(C)

FIGURE 15. MOVED STREAM LOLLEBEEK: (A) COMPLETE; (B) CLOSE UP; (C) CLOSE UP ADJUSTED PROPERTIES

In the figures on the left the newly generated stream can be seen in blue. This new line is generated for all different courses using each their own stream properties. In the first figure the complete Lollebeek can be seen. As the obstacles lay in a specific location, the next two figures are zoomed in. In figure B the stream can be seen with a slope on the right of 5 meter width per 1 meter of height and on the left of 2 meter width per 1 meter height. At the four trees on the right side of the stream (stream flows from the top of the figure to the bottom), the model calculated that the obstacles would be crossed at that side which is the reason why the stream middle line is moved to the left. When looking closely at the last tree on the left side of the stream, the stream curves a bit as well to the right side at that location. In figure C the slope on the left is set to 1/5. The model first calculated that the stream must be moved to the right. After that it calculated that the moved stream crossed another object which meant the stream did not fit between the obstacles. Therefore, the model created a red line as a point of attention for the designer.

## 5.1.3 CHECK WATER PROPERTIES FOR THE STREAM

(A)

(B)

(C)

FIGURE 16. WATER PROPERTIES LOLLEBEEK: (A) LOW DESIRED MAX. DISCHARGE AND HIGH DESIRED MIN. FLOW VELOCITY; (B) LOW DESIRED MAX. FLOW VELOCITY; (C) HIGH DESIRED MAX. AND MIN. DISCHARGE AND HIGH DESIRED MIN. FLOW VELOCITY

The figures on the left show several outcomes of the "Check water properties stream" model. As can be seen in the figures multiple situations were simulated by adjusting the input ranges of the desired discharge and flow velocity. The model returns the locations where the stream does not meet the desired values. Those locations can then easily be found and investigated by the designer by selecting the corresponding layer as defined in Table 2. If the stream does comply to the set requirements, no coloured lines will be generated and the original stream can be seen in dark green. One interesting observation which was made while testing the model was that at a certain location all coloured alarm lines were generated which is in reality not possible due to the fact that a singular value cannot lay below and above a given range. The reason for this is that at that certain location the stream bed was located higher than the surface level which made it impossible for the model to calculate the formulas. As this is a very clear indication that the stream is not well designed, this feature remained in the final design of the model.

5.1.4 CREATE STREAM BED LINES

In Figure 17 the creation of the stream bed lines can be seen. As shown in the figures the stream bed line follows exactly the direction of the sketched middle line. Also, the given stream bed width is followed across the complete stream. From these outer stream bed lines, the lines which connect the stream profile to the existing surface level can easily be drawn in Civil 3D using the grading tool.
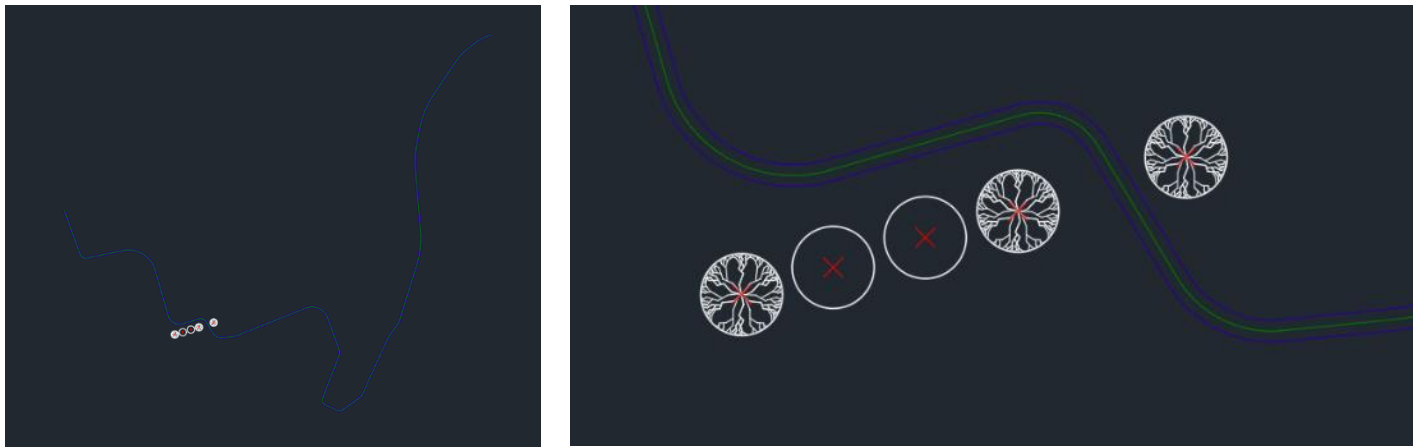
(A)   (B)

FIGURE 17. STREAM BED LINES ACROSS LOLLEBEEK: (A) COMPLETE STREAM; (B) CLOSE UP

5.2 VALIDATION AND QUALITY ASSESSMENT

5.2.1 VALIDATION

Validation is done by measuring the output lines of the models. For example if the input value states that the stream bed width is 4 meters, the distance between the stream bed lines should be 4 meters at all locations across the stream. This was the first indication that the models generate the correct output. Another strategy for validating the models is by comparing the output of the models to the final design made by the designers at Sweco. When using the "Check water properties for the stream" model on the Lollebeek with the same input as the actual Lollebeek, one part of the stream contained all four different types of layers which means, as described in 5.1.3 Check water properties for the stream, that the stream bed is located above the surface level. When looking at that location of the stream and compare it with the actual design of the Lollebeek, which is both shown in Figure 18, it can be seen that around that location the actual design has different types of interventions in order to prevent the stream profile from becoming too small or the stream bed from laying too high. Examples of intervention taken in the

actual design are raising the surface level and placing course woody debris upstream. At the location where the course woody debris is placed the stream bed drops with 20 centimetres which is significantly more than the slope of the remaining parts of the stream. Due to the presence of the wood the water in the stream slows down which means the stream can descent faster while keeping the flow velocity within the desired range. Because of this drop of 20 centimetres, the stream has the ability to keep discharges in the desired range downstream.
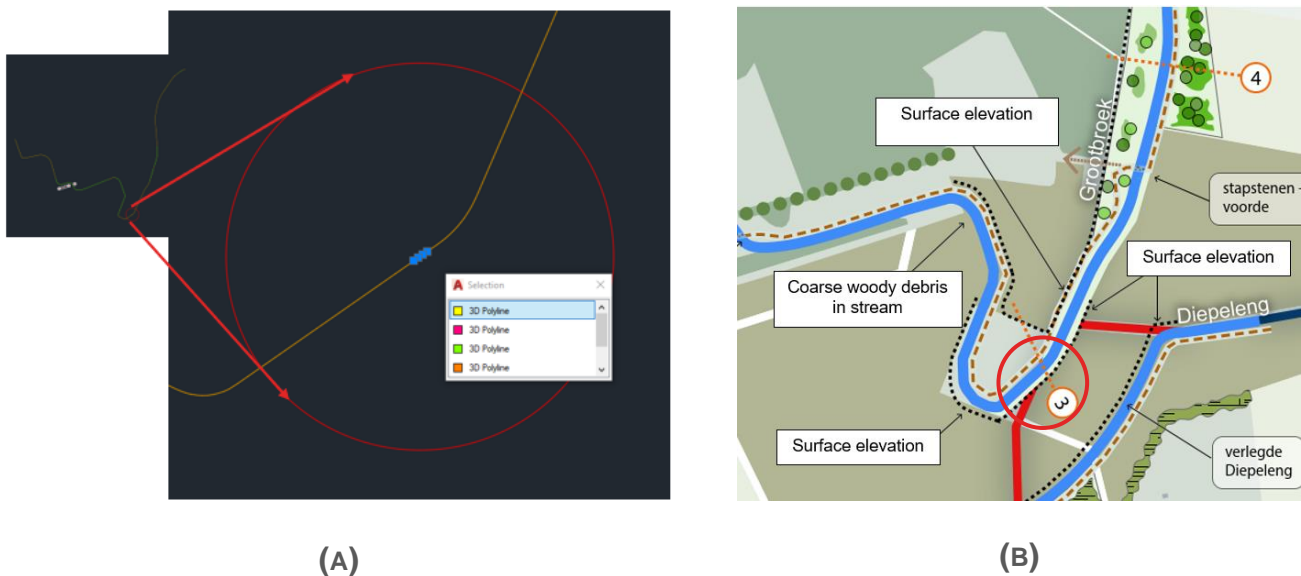

(A)   (B)

FIGURE 18. VALIDATION USING COMPARISON: (A) LOCATION STREAM BED ABOVE SURFACE LEVEL; (B) LOCATION INTERVENTIONS TAKEN IN ACTUAL DESIGN OF THE LOLLEBEEK (SWECO, 2020)

5.2.2 QUALITY ASSESSMENT

In Table 3 the identification of the used variables in the models can be seen. The variables are shown with the first two categories of the NUSAP method, numeral and unit. As can be seen in the previous section, the models create lines as output. This is the reason why output variables are not taken into account in the table. The location of the lines can however be expressed in coordinates with meter as its unit. Regarding the third category in the NUSAP method spread, the uncertainty of those output lines can be derived from the input variables. This spread is mostly caused by the measurements done in order to get the data for the surface and obstacle location. Another major factor which increases the uncertainty of the output lines is the Strickler coefficient. The reason for this is that this factor is always an estimate of the actual situation which is dependent on future factors such as how often the stream is actually maintained.

TABLE 3: IDENTIFICATION OF THE VARIABLES USED IN THE MODELS

Variable	Numeral (example numbers)	Unit
Coordinates obstacles (x,y)	(199460.355, 387909.162)	$(meter, meter)$
Surface height (z)	23.514	$meter$
Slope across length	0.3	$meter/kilometer$
Slope across width	1/5	$meter/meter$
Stream bed width	4.0	$meter$
Starting height stream bed (z)	21.7	$meter$
Range discharge	0.2-1.125	$meter^3/seconds$
Range flow velocity (u)	0.2-0.8	$meter/seconds$
Strickler coefficient (k_{st})	15	$meter^{1/3}/seconds$

The last two categories of the NUSAP method, assessment and pedigree, were investigated during the expert elicitation. During this expert elicitation two design experts, one water expert and one technical manager were present. These experts combined have all knowledge needed in order to create a complete overview of the quality of the created models and the method of PD itself. As these experts come from several departments and each expert valued the model regarding their own expertise, some categories were given multiple scores as can be seen in Table 4. Each category in the pedigree matrix is discussed below the table.

TABLE 4: PEDIGREE SCORES PER CATEGORY

Category	Score
Proxy	2
Empirical	3-4
Theory	4
Method	2-3
Validation	4

5.2.2.1 PROXY

The question if the model generates the desired output can easily be answered with a no. At the end of the design process a complete design of the stream must be present which the models do not provide. The experts state however that the models do help getting towards this complete design and speed up the process of designing. Therefore the models can be considered a helping tool in order to get to the final design but not a finalized designing method. The expert from the water department states on the other hand that the desired output varies with each project which means it is very unlikely a model can actually reach a score of 4 in this case. Other reasons given by the technical manager are that a model cannot take over some design choices which are arbitrary and that the decoration around the design differs every time which means it is very hard to model. In the end the experts agreed on a score of 2, because the model does generate output which is very useful in the design process itself.

5.2.2.2 EMPIRICAL

In the category empirical the models score different when looking at the water features and the designing features of the model. When concerning the designing features the model uses large direct measurements. The data comes from measurements done with very precise equipment which overall has deviations of approximately several centimetres. Some examples of those measurements can be seen when finding the coordinates with corresponding height of the surface and obstacles. This is the reason why the experts valued the models a 4 when looking at the design features. When looking at the water features there is one variable which keeps the models from getting a 4. This variable is the Strickler coefficient which is always set to be an estimate. As the rest of the variables of the water features are direct measurements the model still scores a 3.

5.2.2.3 THEORY

In the category theory there was a fast consensus between the experts as the model does not rely on a lot of theory. The only theory used in the models is the theory of Strickler. According to the expert from the water department this is a very well established theory which is used a lot in the design processes of all types of streams. Therefore the models score a 4 when looking at this category.

5.2.2.4 METHOD

The category method created a point of discussion between the experts. The advantages of using the method of PD according to the experts is that it takes over a lot of repetitive tasks the designers normally do manually. One expert on the designers' team states that the designed model can be trusted more than the designers themselves due to the fact that human error can be avoided. On the contrary the technical manager states that the models cannot be trusted if they have not been in practice for a while. The trust in the models must be built up by using them. This was also substantiated by the theory in 2.1 Characteristics and use-cases of parametric design. Another disadvantage the experts noticed is that the preparation before being able to use the model takes a lot of time as well. They state that if the models are designed further this could be reduced. The expert of the water department values the method a 3 as the water features inside the model are reliable and commonly accepted. For the designers and technical manager, the score remains a 2 and can be boosted up to a 3 at the moment when more trust in the method is generated by getting more acquainted with them.

5.2.2.5 VALIDATION

Due to the fact that the models are designed for automation of the current design process, the models can very well be validated. According to the experts the outcome of the models can easily be checked for strange features in the new design. During the expert elicitation the original design of the Lollebeek was compared to the design the models created. Both methods showed the same points of attention on the stream. Another argument given by the water expert was that the output of the model is always checked by a model which calculates the discharges and flow velocities more thoroughly. In this way faulty final designs are highly unlikely. The experts value this category a 4 as no reasons could be thought of to bring the score down.

5.2.2.6 SUMMARY QUALITY ASSESSMENT

Overall, the quality of the models can be considered quite good. The limitations of the models lay mostly in the proxy and method category. This comes due to the fact that the models are not that well developed yet. A lot of parts can still be added to the models in order to create a more complete process. Another reason why the models score low on method is due to the fact that the method is relatively new. By gaining more trust by the designers in the models this score can go up.

6. DISCUSSION

In this section the results of this project are critically discussed. The limiting factors of the models and method will be shown which first done by reflecting on the process of creating the models, followed by the reflection on the resulting models and possible limiting factors of the models in future use. Based on this chapter a recommendation can be written on how the models should be improved if further research is done.

There are many ways of modelling the design process of a water stream. One of the first ideas, and at that time the most obvious was to calculate the design of the stream using the complete surface of the project area. By using the complete surface, the model could be able to calculate the exact intersections between the slope of the stream and the surface which means an precise final design could be created. A few test runs showed that it is indeed possible to create the design of the stream in this fashion however it takes a lot of time for the model to run. The software was jamming frequently for a quite small design which meant that another way of calculating the design had to be thought of. This problem was solved by using only the surface height at the location of the already sketched line. In this way the model did not have to process all points on the surface which meant the models could process the data a lot faster. The downside which comes with this method is that a precise design of the stream is not possible anymore. An indication can be given, but for a complete precise design the designer still needs to do some designing manually. Another problem or point of discussion which occurred frequently while creating the models was that it could never be certain that the 'best' method was used when writing the scripts. As said, there are many ways in which the models could be made which could lead to different results. Regarding the working out of the models another issue occurred during the process which could still have influence on the outcome. This is the fact that a lot of possible ways were inserted into the models which meant the models grew very fast. This resulted in less clarity about what was still necessary for the models to still be able to work and what lines and nodes had become irrelevant. This means it can be possible to increase the speed of the models by removing nodes without changing the outcome.

Regarding the results of the models there are multiple points which can be critically reflected on. The first point is that the outcome might not always be the desired

outcome. This is due to the fact that every project is different which means a different result is wished for. Another thing which needs to be considered when wanting to work with the models is if the setting up of the input variables and finishing of the design based on the outcome of the models weights up again the current manual way of designing. For small projects it might not always pay off to use these models due to the fact that it might take more time in the process compared to manual designing especially when one is not known with using the models. This comes with the fact that the resulted models are not ready yet to be operated without a manual. There are a lot of possible factors which could cause a flawed design if those are not set to the correct value or handled in the correct manner.

Factors which could cause limitations in future use have mainly to do with the fact that the desired design is different every project. Often different profiles are needed for the design of a stream which the models do not provide or obstacles are not only considered to be trees with a circular forbidden area but can also be cables for example. Another limiting factor is that the models can only give an indication about the possible design of the stream. The models can be used as a tool in order to get to the final design but it cannot be used to create a complete final design on its own. The last limitation which is important to mention is that speed could cause issues in future projects as the size of the projects differs every time. If the project spans over an area which is too large for the models too handle the software becomes unmanageable.

7. CONCLUSION

In this section the answers to the research question in 3.3 Research questions are given. This is done by first answering the main research question and second the sub-questions. First the research question will be stated whereafter the answer to the question will be given.

- **How can the design of water streams be automated?**

The design of water streams is automated by using PD in the design process. The models which represent the PD process are created using Dynamo. The models give an indication of where the stream can possibly be located and where it cannot. On top of that the models indicate possible points of attention regarding flow velocity and discharge. Last but not least the models generate parts of the profile needed for the final design of the stream. All these parts combined automate and speed up the process of designing water streams. This is done by taking away iterations between departments and manual tasks in the design process.

  - What existing knowledge is there already in practice and can be used to model water streams?

The knowledge used in order to model the streams comes from the theory in section 2. Theoretical framework and from interviewing experts at Sweco. The theory of PD can be found back into the structure of the models. The models are built up in a way that the output variables are interconnected with the input variables which results in less time spend on repetitive tasks in the design process. The content of the models is mainly based on the interviews done with multiple Sweco employees.

  - What features have to be in the Keutelbeek model in order to create a parametric template for other streams?

In order to be able to create a template from the Keutelbeek model it was ensured that no specific unique design choices from the Keutelbeek project were present in the models. The features which are present in the Keutelbeek model are thus features which must be present in every stream such as being able to see if a stream fits. In this way it was very easy to use the Keutelbeek model for other streams, for example the

Lollebeek. By using the model on the Lollebeek the models became more complete which means the template became more complete.

- o Which and in what form must the input and output be in order to be usable?

All input needed for the models can be seen in Table 3. These input variables can be found in reports and sketch designs made earlier about the water properties of the stream and other design properties or wishes. The output is in the form of lines which can give an indication where the stream does not comply to the design requirements and of lines which can be used in the final design and in the further creation of the complete final design.

- o How can de designed model be validated and does the model pass the validation?

The designed model is validated by comparing the design of the Lollebeek which was made by the models with the design made with the usual manual way. Both methods showed the same points of attention which means that the models pass the validation. Another method of validation used during the creation of the models was by measuring the output lines. At the moment the lines were at the correct location the next part of the model could be created. The results of the quality assessment are promising. As the lower values are due to the fact that the models are not developed far enough or based on trust, the quality of the models can be considered relatively high.

8. RECOMMENDATIONS

In this section will be explained what can be done in the future in order to further develop PD into the design process of water streams and possibly other type of projects as well. On top of this, advice will be given on how the designed models can best be used for a successful outcome.

There is still a lot of potential for further research when considering the automation of the design process in water streams. The next step in the process which is already in development is to be able to generate and calculate with different types of profiles as this is a factor that differs almost with every project. By standardizing the input to data, the models can process an unlimited amount of different profiles. The first results of working with this method can be seen in Appendix C. Other possible future development also lays beyond the implementation of PD in the design process of water streams only. In the construction of dikes and roads similar characteristics, which are alike to the characteristics of water streams, can be seen such as long tracks with a single profile. This makes it very likely that introducing PD into those design processes would be successful as well.

As discussed earlier in

1. Introduction, the end goal of using this method is not only being able to generate a complete design of water streams, but also to implement the so called soft-input into the design process from which immediately a new design can be created in order to be able to visualize different types of design options for clients. In this way the clients can express more clearly what their vision is and what they want to achieve with it. Moreover, a flawed design becomes less likely due to the fact that communication becomes more clear.

In order to make it as easy as possible for the designers to use the models, a manual was created which can be used if the designers get stuck or some part of the process does not function. The manual describes in detail how the models should be used and what should be done before, in between and after the operation of the models. The manual is added to this report and can be found in Appendix D.

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APPENDIX A

(A)
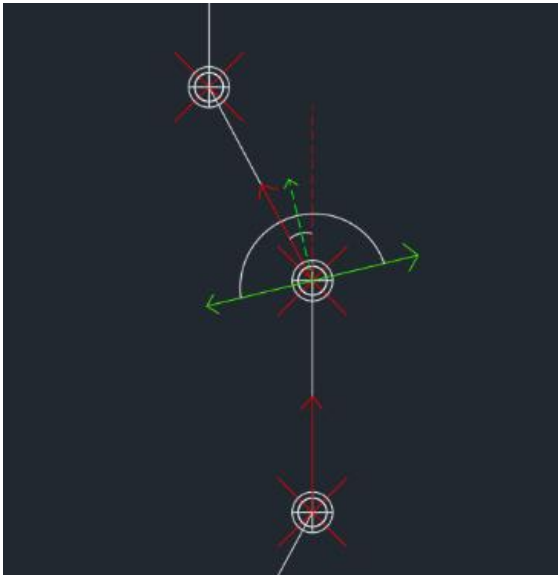
(B)
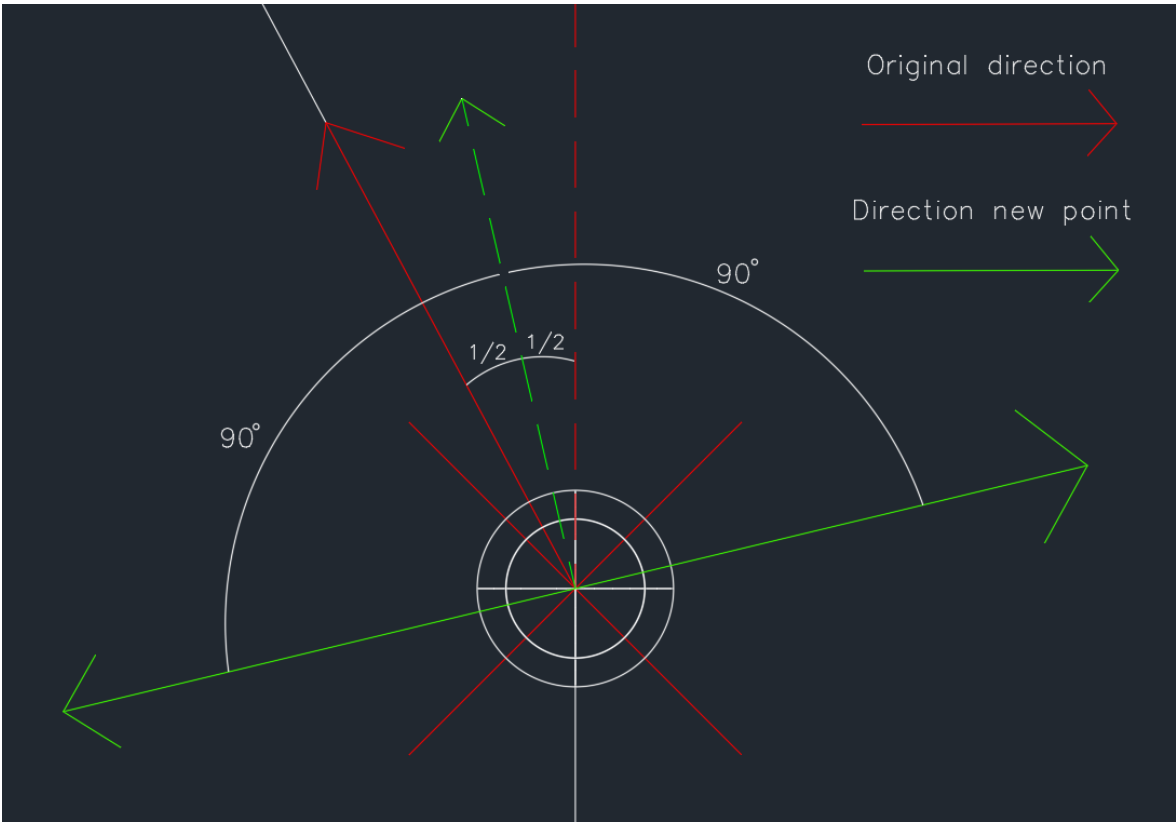
(c)

FIGURE 19: DETERMINING DIRECTION NEW POINT

APPENDIX B
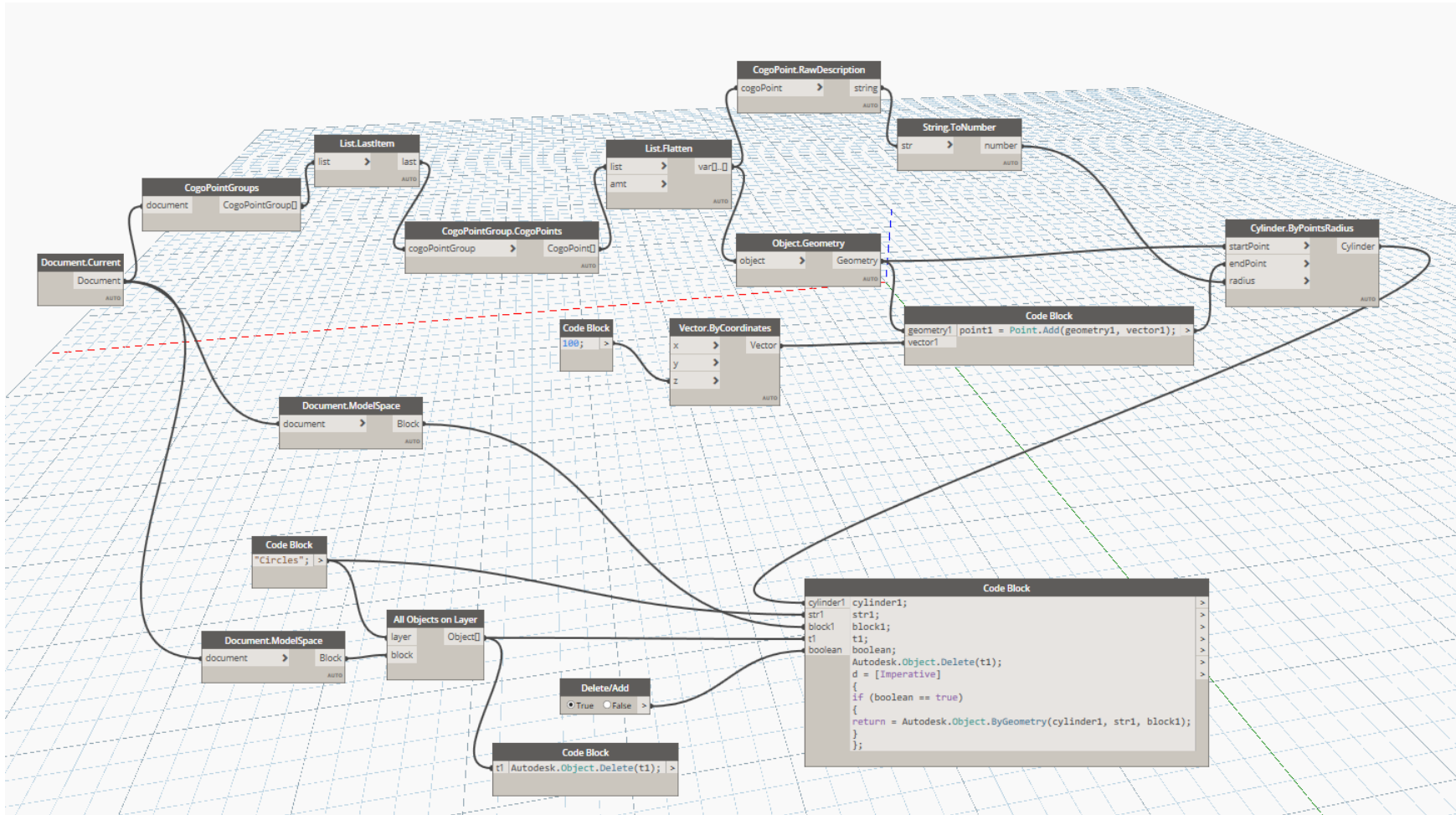
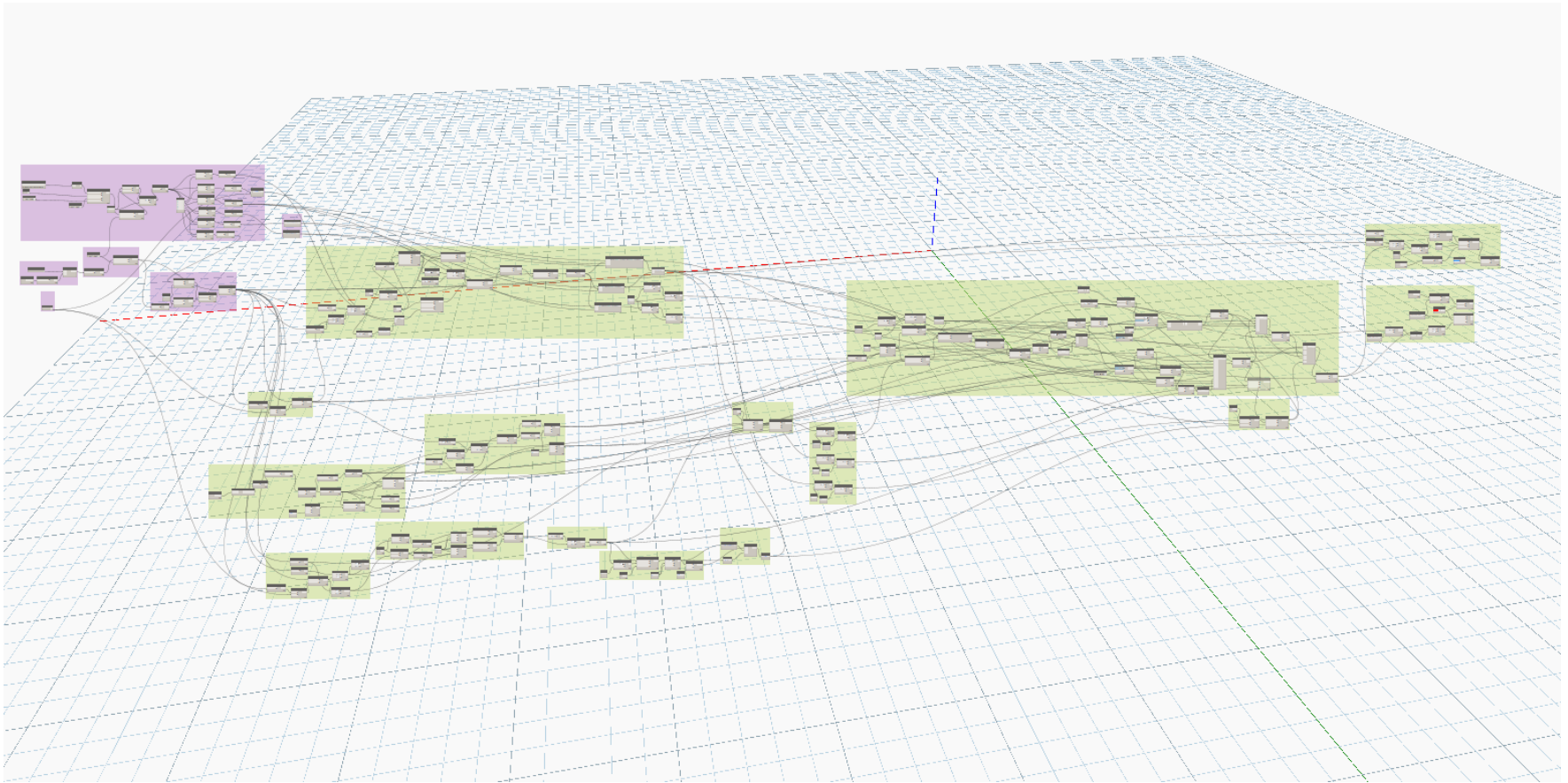**FIGURE 20: OVERVIEW DYNAMO MODEL "CIRCLES AROUND OBSTACLES"**

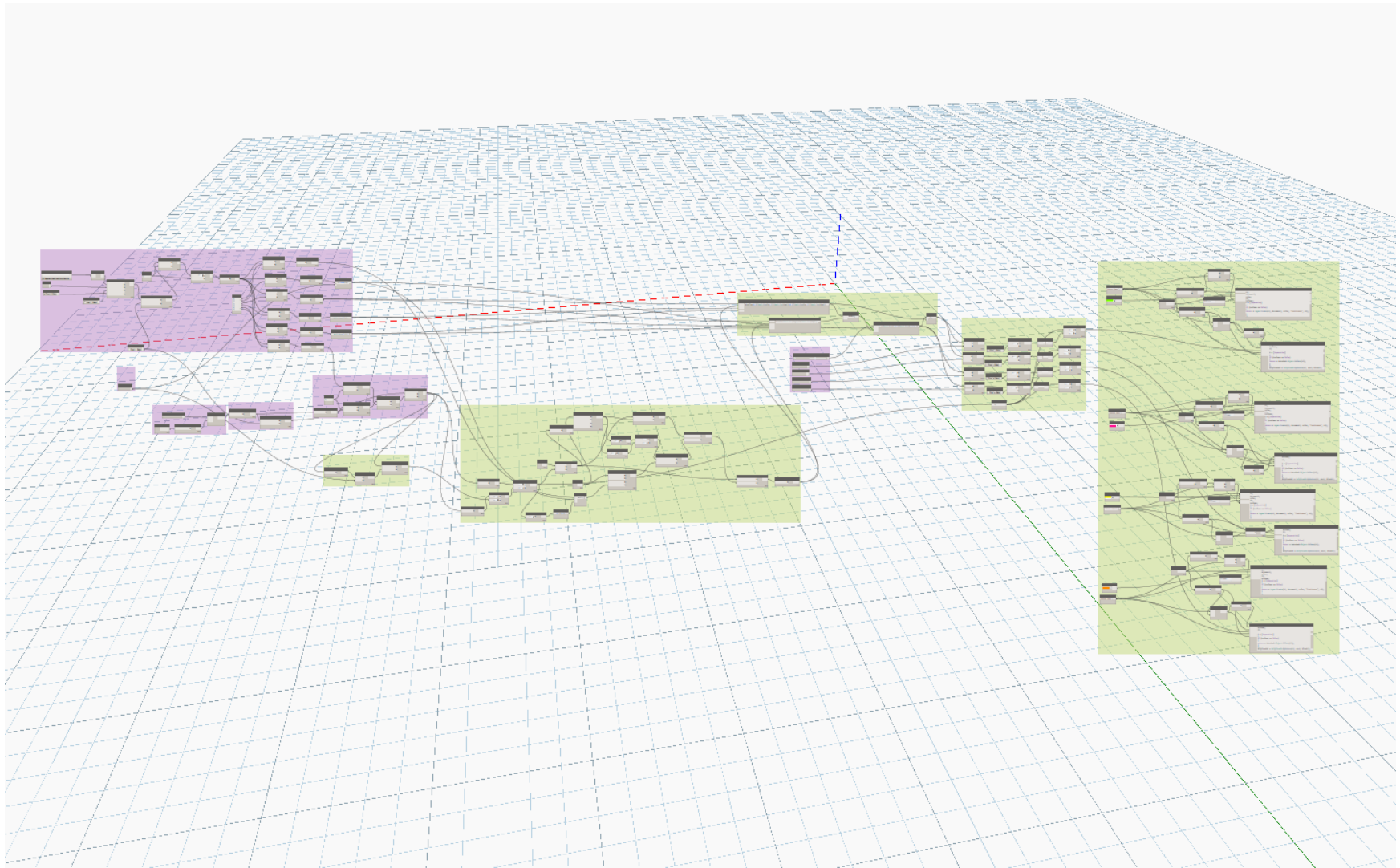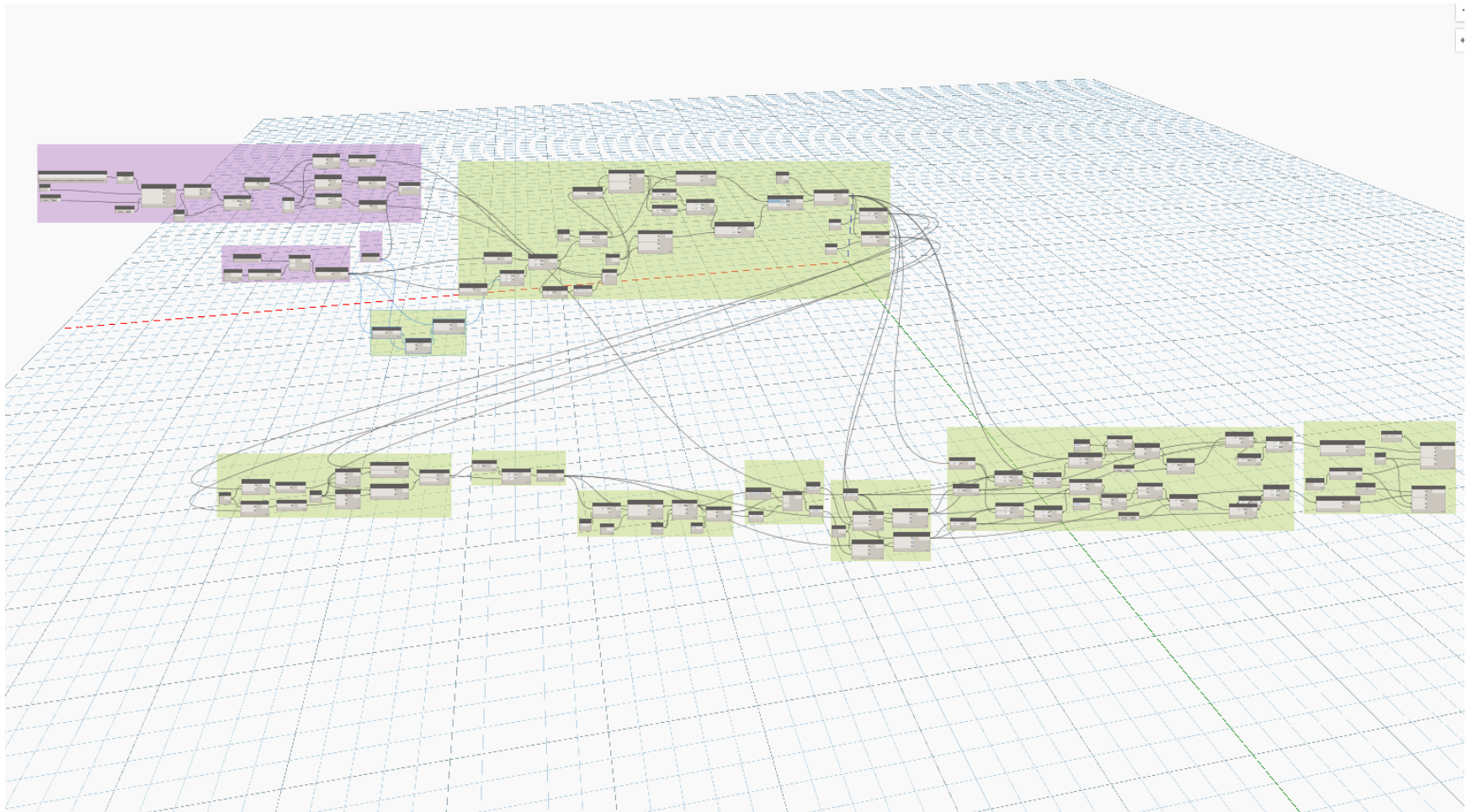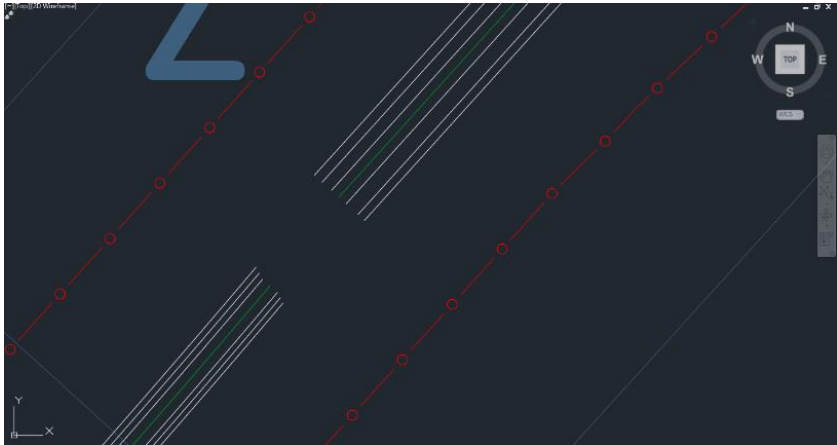**FIGURE 21: OVERVIEW DYNAMO MODEL "MOVE STREAM IF OBSTACLE IS CROSSED"**

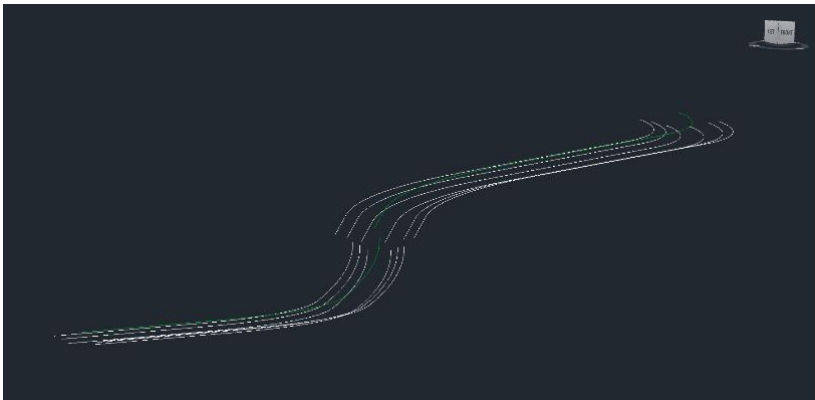**FIGURE 23: OVERVIEW DYNAMO MODEL "CREATE STREAM BED LINES"**

APPENDIX C

(A)

(B)

(c)

FIGURE 24: STREAM WITH SPECIFIC PROFILE: (A) COMPLETE PROJECT AREA; (B) TOP VIEW;
(C) 3D VIEW

APPENDIX D

Below the guidelines can be found on how the models should be used and what factors need to be considered. This manual was designed to take away possible errors during the using of the models and give answers when designers get stuck. The manual is in Dutch as the employees at Sweco Eindhoven are in general Dutch.

In dit stappenplan wordt uitgelegd hoe de bedachte dynamo modellen gebruikt moeten worden in het ontwerpproces van een beek. De modellen zijn bedacht als ondersteuning van het proces en kunnen snel een indicatie geven over de haalbaarheid van een bepaald ontwerp. Het is aan te bevelen om na het verkrijgen van een ontwerp dat is gemaakt met behulp van de dynamo modellen om een laatste controle te doen op de correctheid van het eindontwerp. Er wordt in deze situatie vanuit gegaan dat de volgende randvoorwaarden bekend zijn:

- Grenzen projectgebied
- Coördinaten van obstakels met bijbehorende radius waarin geen constructie mag worden geplaatst
- Een eerste SO met correcte coördinaten
- Gewenste verhang, bodembreedte en helling $\frac{1}{m}$ per tracé
- Bodemhoogte start tracé
- Maximale en minimale gewenste debiet en stroomsnelheid
- Strickler coëfficiënt K_{st}

Zodra de bovenstaande waardes bekend zijn kunnen de onderstaande stappen worden uitgevoerd. Hierin wordt gebruik gemaakt van de dynamo player. Deze is te vinden in het tabblad "Manage" in Civil 3D.
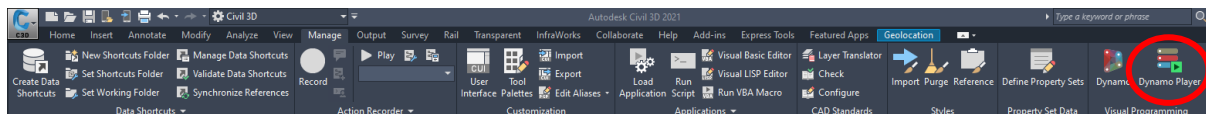
 Zodra de player wordt geopend kan hetvolgende worden bekeken:

Dynamo Player
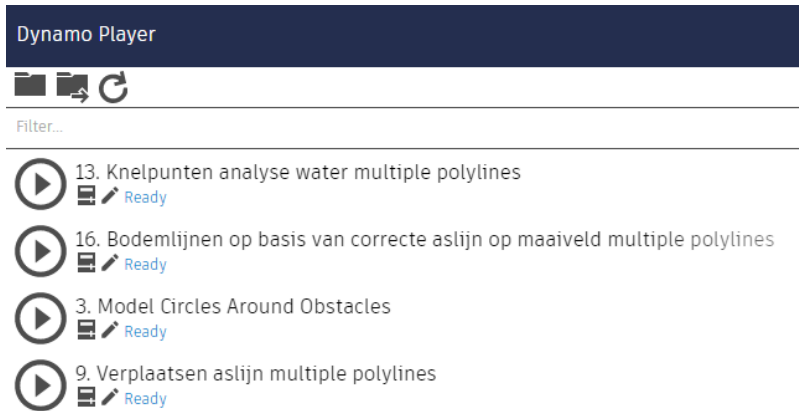
Selecteer met de knop ▣ het correcte bestand met de te gebruiken modellen. Om direct het model te gebruiken druk op ⊙ en om input waardes te wijzigen druk op ▤. Om het model aan te passen in Dynamo kan de knop ✎ gebruikt worden. Dit is echter niet aan te raden.

Volg de onderstaande stappen voor het parametrisch ontwerpen van een beek:

1. Importeer surface (maaiveld) van projectgebied in Civil 3D.
2. Markeer obstakels met punt en geef als beschrijving de bijbehorende radius waarin geen constructie mag worden geplaatst.

| Point Number		Raw Descripti...	Full Descript...
⊕	1	7.5	7.5
⊕	2	7.5	7.5
⊕	3	7.5	7.5
⊕	4	7.5	7.5
⊕	5	7.5	7.5

3. Gebruik model "Model Circles Around Obstacles".
- Gebruik de knop Delete/Add om de cirkels toe te voegen bij het begin van het ontwerpproces en te verwijderen zodra het ontwerp klaar is.

Dynamo Player

‹ ↻

⊙ 3. Model Circles Around Obstacles
   ▤ ✎ Ready

✓ Delete/Add :
   [▮]
   True
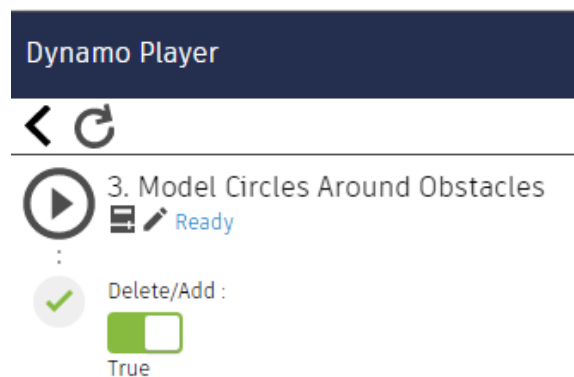
4. Schets eerste polylijn/featurelijn → (maak featurelijn van polylijn).
- Dit is de lijn die volgt vanuit het SO
- Voor een sneller proces gebruik de optie "weed" om minder punten op de lijn te genereren.
- Zorg er voor dat de aslijn op een aparte layer ligt waar niks anders op staat.
5. Leg featurelijn op hoogte van maaiveld/surface.
- Controleer in object viewer voor opvallende hoogtes (i.v.m. mogelijke gaten in surface)
6. Gebruik command "explode" op featurelijn voor het creëren van 3D Polylijn.
7. Gebruik command "break" voor het opdelen van lijn in verschillende tracés.
- Verdeel de lijn zo dat dat de er één standaard profiel is per lijn
8. Vul Excel template in.
- De gekleurde vakken worden berekend met behulp van de niet gekleurde vakken. Alleen de niet gekleurde vakken hoeven dus ingevuld te worden.
- Voor de kolom lengte, selecteer de betreffende lijn in Civil 3D en ga naar "properties". Lees daar de bijbehorende lengte af en vul deze in de excel template in op een afgerond heel getal. Tracés mogen niet even lang zijn. Mocht dit wel het geval zijn, pas dan een van de twee tracés aan in Civil 3D.

	A	B	C	D	E	F	G	H	I	J
1	Tracé	Hoogteverschil bodem/maaiveld start	Verhang	Bodembreedte	Slope links (m)	Slope rechts (m)	Lengte	Bodemhoogte start tracé	Bodemhoogte eind tracé	Hoogte maaiveld start tracé
2	2	0.8	0.09	4	5	2	401	21.7	21.66391	22.5
3	3	2.03609	0.09	4	2	5	330	21.66391	21.63421	23.7
4	4	1.18579	0.09	4	2	5	778	21.63421	21.56419	22.82
5	5	0.72581	0.09	4	2	5	616	21.56419	21.50875	22.29

9. Gebruik model "Verplaatsen aslijn multiple polylines".
- Vul bij "points per meter" in hoeveel punten per meter het model moet berekenen. Hoe hoger dit getal hoe preciezer het model is, maar ook hoe langer het duurt.
- Bij "Layer with only middle lines", vul de laag in (zie stap 4) waarop de geschetste lijn zich bevindt.
- Selecteer bij "File Path" het ingevulde Excel template van stap 8 in en pas waar nodig het vak "Bladnaam" aan.
- Voor het snel aan kunnen passen van de waardes in de Excel template vink "Show excel file" aan.
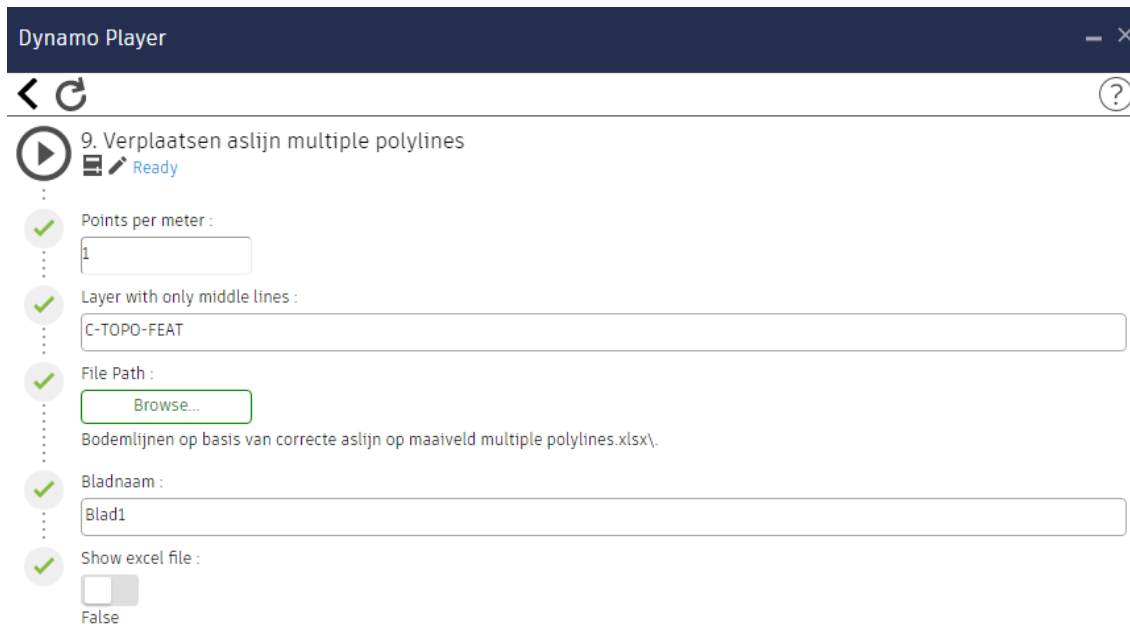
10. Controleer op verschillen geschetste lijn en gegenereerde lijn.
11. Bij verschillende lijnen schets nieuwe vloeiende lijn op basis van gegenereerde lijn.
- Zorg dat ook deze lijn op de hoogte ligt van het maaiveld.
12. Herhaal stap 10, 11 en 12 totdat nieuwe lijn hetzelfde blijft als geschetste lijn.
13. Gebruik het model "Knelpunten analyse water multiple polylines".
- Vul de verzamelde randvoorwaarden in.
- Voor de overige instellingen zie stap 9.

Dynamo Player ─ ✕

< C   (?)

▶ 13. Knelpunten analyse water multiple polylines
    Ready

k_st :
15

Minimal discharge Q :
0

Minimal flow velocity u :
0.2

Maximal flow velocity u :
0.8

Maximal discharge Q :
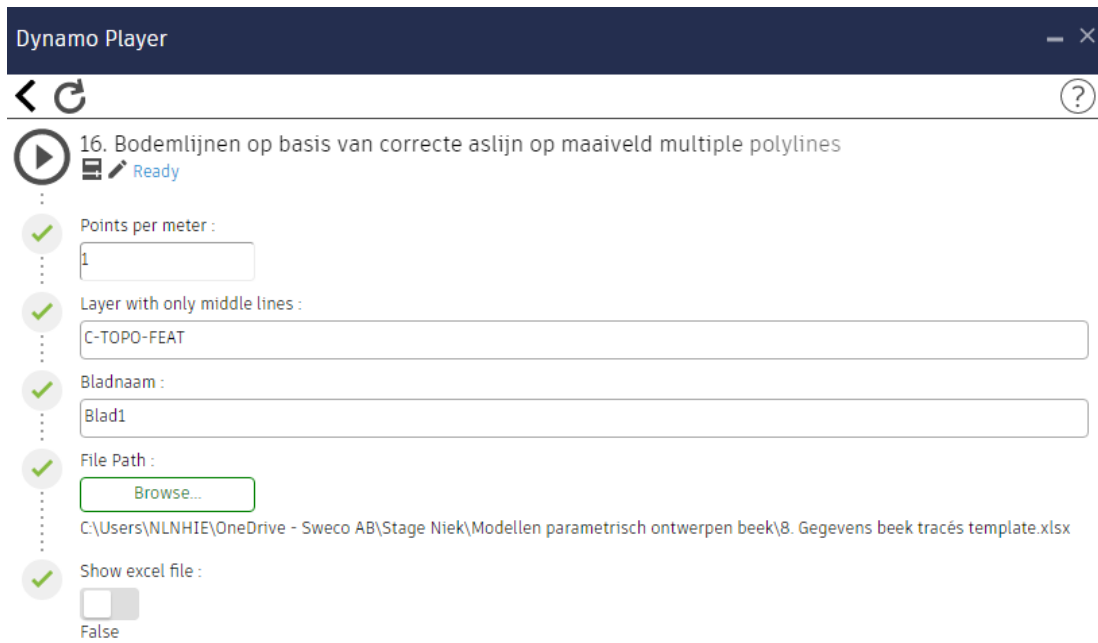1.125

Layer with only middle lines :
C-TOPO-FEAT

Points per meter :
1

File Path :
Browse...
Gegevens beek tracés template.xlsx .8\.

Show excel file :
True

Bladnaam :
Blad1

14. Controleer op nieuwe gekleurde lijnen (alle kleuren als output → bodem beek boven maaiveld).
15. Bij gekleurde lijnen, check bij water welke waardes (profiel of ligging) aangepast moeten worden en ga terug naar stap 10.
16. Bij een lijn zonder knelpunten gebruik model "Bodemlijnen op basis van correcte aslijn op maaiveld multiple polylines".
- Voor instellingen zie stap 9.

Dynamo Player

16. Bodemlijnen op basis van correcte aslijn op maaiveld multiple polylines
Ready

Points per meter :
1

Layer with only middle lines :
C-TOPO-FEAT

Bladnaam :
Blad1

File Path :
Browse...
C:\Users\NLNHIE\OneDrive – Sweco AB\Stage Niek\Modellen parametrisch ontwerpen beek\8. Gegevens beek tracés template.xlsx

Show excel file :
False

17. Gebruik de grading tool om talud aan beide kanten te creëren.
18. Laat ontworpen beek controleren door afdeling water.