SAVING TIME

Using parametric design

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Summary

1. Research statements

1.1 Problem statement

As a full company, with corresponding overhead costs, the average cost to hire a designer working for Witteveen + Bos is €90 per hour. In comparison, an experienced self employed designer working from home with a yearly income of €100.000 will do the same job for roughly €60 to €70 per hour (€100.000 / (36 x 40) = €69,44 per hour). Therefore an employee at Witteveen + Bos is required to be 30% more efficient at their job in order to remain competitive in the market. Some of this efficiency is naturally gained from working in a team, but a large part must be achieved through more efficient workflow. This requires frequent reconsiderations and optimizations of the design process.

1.2 Goal of the research

The goal of this research is making the design process of sewer systems more efficient by utilizing the developments in designing software, automizing design steps and optimizing the data transfer between different design software.

1.3 Boundary conditions

This research report is limited by the licenses available to Witteveen + Bos employees. Therefore the software used in this report is limited to:

Civil 3D	3D CAD drawing software
InfraCAD	The Dutch drawing standards plugin for C3D
Infoworks	Software used to simulate the performance of sewer systems
Dynamo for Civil 3D	A plugin for C3D that allows visual programming with Python scripts
Subassembly Composer	Software that allows for the creation of custom subassemblies, which can be used for the creation of Corridors in C3D

Furthermore, the scope of this report was functionally limited to simple free fall sewer systems and structurally limited to chambers and pipes.

1.4 Research questions

1.4.1 Main question

How can the design process of a simple free-fall sewer system be accelerated, using software already in use at Witteveen + Bos?

1.4.2 Sub-questions

- *What is the purpose of a sewer system?*
- *How has the design of sewer systems evolved?*
- *What are the common components of a sewer system?*
- *How can the components of a sewer system be defined?*
- *How are sewer systems currently designed at Witteveen + Bos?*
- *Which design steps are required in order to design a sewer system?*
- *Which new developments in software are available for the design process of sewer systems?*
- *How could these developments be used to further improve the efficiency of design steps?*

2. Introduction to the sewer system

2.1 The purpose of sewer systems

Any living organism on earth is a contained ecosystem. A living organism can be likened to a chemical factory. Raw materials are put into the ‘factory’, molecules are changed according to pre-determined chemical processes into different molecules and in turn the organism thrives. During the conversion waste is generated, which is excreted from the system. The waste can be either solid, or liquid.

Humans, as opposed to most other living organisms on earth, have also started to produce some of their needs externally. Clothes, building materials, cleaning agents, hardware and any other products required for a modern human to thrive are produced by industries. They also convert raw resources into final products. Molecules and/or shapes are being altered into different molecules and/or shapes and during these processes, waste is generated. The waste can be either solid or liquid and is also excreted from the industry.

If waste, whatever the source may be, is not processed, it collects locally and causes long term environmental and sanitary problems. In order to be processed, the waste must be transported away from the direct environment. The consistency of the waste determines the most efficient way to transport the waste. Liquids require less impulse in order to start moving, and therefore move easily under the effects of gravity towards the lowest point available to them. The most efficient way to move liquids is therefore to allow them to move under the effect of gravity from a high elevation to a lower elevation. The desired final destination of the liquid is not always the lowest elevation in the region. Therefore the flow of the liquid must be guided through a system of channels, each of which are locally the lowest available elevation for the liquid.

For liquid waste, or solid waste suspended in a liquid, this infrastructure is called a sewer system. The purpose of sewer systems is therefore to transport liquid waste or suspended solid waste.

2.2 History of sewer systems

Sewer systems are an incredibly old technology. The oldest discovered sewage pipes, made from clay, date to around 4000 BCE. They were found in the temple of Bel at Nippur and at Eshnunna (Burke, The Fluoridated Water Controversy: Unbiased Reference Source & What You Need to Know, 2017). In Europe, it was the Romans who first made a policy of wastewater management and developed the precursors to current sewage systems. The Cloaca Maxima, one of the oldest still existing sewer systems, was supposedly first constructed in 900 BCE. (Hopkins, Bond, & Killgrove, 2007)

Even though the Roman empire at its height used to include parts the Southern Netherlands, it wasn’t until 3 millennia later (in the 20th century) that sewer systems were developed in Dutch cities. The first sewer in Amsterdam was constructed in 1910, after a number of Cholera disease outbreaks forced a reconsideration of the wastewater policy in cities. Some regulations already existed to collect waste from houses, by the so called ‘tonnenboer’, but these primitive methods proved incapable to keep up with the increasing demand from the explosive population growth in cities. (de Vries, 2020)

The first sewer systems in the Netherlands were copied from sewer systems in London and Paris, which in turn were remarkably similar to the ancient Roman sewer systems. They consisted of open sewer channels that were later closed off on top in order to create a separation between civilians and the waste.

At first, waste water was still dumped directly into surface water (preferably some distance from the cities). The pollution both from human waste and in increasing numbers from industrial waste caused such environmental pollution in Dutch surface waters, that during the 19th and early 20th century the rivers in the Netherlands turned from rich fishing grounds to rotting sewer channels. Early attempts to tackle the environmental pollution were often fended off due to economical considerations. Municipalities were often unwilling to bear the heavy costs involved in wastewater treatment and industries were just as unwilling to pay for the expenses. Due to increasing pressure from unhappy civilians simple unexpensive treatment methods were implemented, like settling tanks. However it wasn't until 1967 that the first true biological wastewater treatment plant was built. These treatment plants were funded by state subsidies. (van Loohuizen, 2006)

Environmental laws were implemented to prevent further pollution of the Dutch surface waters. The 'Wet Verontreiniging Oppervlaktewateren' (implemented in 1970) made it so permits were required in order to be allowed to dump wastewater into surface waters. This law has been replaced by the much broader 'Waterwet' in 2009. The older 'Hinderwet' from 1875 gave some protection against nuisance from the dumping of waste. It required replacement with the 'Wet Milieubeheer' in 1993 to also include environmental protection, rather than just nuisance. (Geels, 2006)

Nowadays dumping of wastewater without treatment only happens in very strict, mitigating circumstances and wastewater treatment facilities have become a staple in the Dutch wastewater management.

2.3 The main developments in sewer systems

2.3.1 Developments in wastewater treatment plants

The first wastewater treatment plant dates from 1904 in Tilburg, called the 'Rijksproefinstallatie'. This plant was more or less a test of the wastewater treatment technologies of the time. The first wastewater treatment plants only used basic settling tanks to filter the worst sediments out of industrial wastewater before dumping said wastewater into surface water bodies. Increasing demands and regulations on the treatment of wastewater have really pushed research into the treatment of wastewater to the point where current wastewater treatment plants can safely and efficiently extract enough pollutants from wastewater to prevent negative environmental effects from dumping the treated wastewater into the environment (Geels, 2006).

Industries started to be held accountable for their own waste, therefore industries directly fund the treatment plants of their own wastewater. For this reason industrial wastewater treatment plants are usually custom built really close to the source of the wastewater and usually only treat the wastewater from either a single industry, or a small collection of industries. The expected pollutants and the concentration of said pollutants is therefore predictable, allowing for a very specialized treatment of said wastewater. The sewer system draining industries are called industrial sewer systems and are under the purview of the industries (Geels, 2006).

The communal waste came under the purview of the municipalities, since they are the governing bodies of the civilians living within these municipalities. In order to be cost-efficient, the municipalities upscaled treatment plants into very large plants treating the communal wastewater from large areas. Municipalities still rather upscale an existing treatment plant rather than build a new one. New sewer systems are therefore usually designed with fixed drainage locations towards an existing wastewater treatment plant in mind. The sewer systems draining towards communal wastewater treatment plants are called communal sewer systems and are under the purview of the municipalities (Geels, 2006).

There is an increasing realization that resources are finite and therefore that industries and households should become more sustainable. A large part of sustainability is the reutilization of waste. Phosphate is already often extracted from communal wastewater and reutilized as a fertilizer in agriculture. Many industries are investing into the reutilization of CO_2 and leftover heat from wastewater. There is a trial running in Stockholm to attempt to extract leftover heat from households. And finally it is possible to extract polymers, cellulose and alginate-like substances. Whether or not these methods are implemented is usually a matter of the economic feasibility of the process, which in turn depends on the demand of the resource and the cost of the extraction of said resource.

2.3.2 Developments in sewer design

Early sewer systems were built simply to drain water from areas in order to mitigate complaints from local residents. Little regard was had for the consistency of said wastewater or for where the wastewater was drained to. This changed with the advent of wastewater treatment. Sewer systems were increasingly connected to the wastewater treatment plants. Whereas industrial wastewater treatment plants were generally constructed specifically and locally for each industry, communal wastewater plants were increasingly upscaled. Communal sewer systems were routed towards these communal treatment plants.

When communal wastewater treatment plants started to use bacterial colonies in order to treat communal wastewater, problems arose during rainfall events. The rainfall could dilute the wastewater to such an extent that the bacterial colonies starved from lack of nutrients. On top of this, due to the large drainage area leading to a communal wastewater treatment plant, a heavy rainfall event could cause a larger discharge towards the treatment plant than the plant was able to handle. At first the problem was mitigated by constructing overflow channels that would discharge the overflow directly to surface water bodies during heavy rain events. This method circumvents the treatment plant and therefore would cause undesired pollution.

Therefore a development was introduced where increasingly sophisticated methods were created to remove excess storm water from the communal sewer. Pollution of surface water could never be fully mitigated, however. The latest evolution in this process is therefore to separate the storm drainage from the communal sewer altogether. The older systems are called combined sewer systems and the new sewer designs are called separated sewer systems. The sewer system discharging rain water is called the storm sewer, the sewer system discharging from households is called the sanitary sewer.

Studies have shown that the first discharge from a rain event can still contain undesired concentration of pollutants. These are washed off of surfaces during first minutes of a rain event after a long dry period. Improved separated sewer systems therefore have some method to drain this first discharge from the storm sewer into the sanitary sewer. These improved separate systems are only rarely used yet.

Most of the sewer system in the Netherlands is still composed of combined sewer system, due to the longevity of sewer systems. Whenever the old sewer is ready for replacement and when it is technically possible, these old systems are replaced by separated sewer systems. New communal sewer systems are designed as a separated system by default.

Functionally, the most efficient way to transport liquids has always been to utilize gravity. The same is true for transporting wastewater. Therefore most sewer systems are still 'free-fall' sewer systems, where the propulsion of the wastewater is generated by allowing the wastewater to run downslope throughout the sewer system. The advent of large communal wastewater treatment plants has caused an increase in the distance that wastewater must travel to reach the treatment plants. Utilizing free-fall alone is therefore often not possible, because the intake at the wastewater treatment plant would have to be located too deep below surface level to make the system viable. Therefore sewer systems that have to transverse large distances make use of intermediary pumps to draw the wastewater to a higher elevation along certain points in the sewer chain.

Sometimes a fully pressurized sewer system will utilize only pressure to transport the wastewater. These pressurized sewer systems have their own set of difficulties to overcome however. Since a fully pressurized sewer pipe is filled only by wastewater, without ready access to aeration, undesired anaerobic bacterial reactions can generate dangerous gasses within the wastewater. On top of that, any leak within a pressurized sewer pipe can quickly turn much worse because of the pressures involved. The resulting pollution is also more widespread due to the pressure, requiring expensive remediation of the surrounding soil. Pressurized sewers are therefore generally avoided if possible in the Netherlands.

2.3.3 Developments in sewer pipes

Creating sewer systems using pipes instead of channels proved less labor intensive and therefore more cost efficient and is still the most widely used method of creating new sewer systems. Early sewer pipes were made from clay and often were constructed on site. Current technology allows for precast pipes. The most easy to cast shape of these pipes is the circular pipe. To counter external forces on sewer pipes some other shapes are still occasionally in use. The most common of these alternative shapes are the egg shaped pipe and the mouth shaped pipe ('Ei-vormig' and 'Muil-vormig'). The egg shaped pipe is better at resisting forces acting along the vertical plane, whereas the mouth shaped pipe is better at resisting forces acting on the horizontal plane. Other shapes are not commonly used, mainly because the supply and demand interactions between contractors and suppliers have made the availability of alternative shapes very scarce and therefore much more expensive. A second reason egg-shaped pipes are still somewhat popular, is that the shape of the pipe allows for a faster flow in the bottom of the pipe. The shape is such that the area A is smaller at the bottom of the pipe, therefore the flow is higher ($Q=A*v$). This generates a larger shear stress on particles on the bottom of the pipe and therefore reduces the depositing of suspended solids on the bottom of the pipes. These pipes are therefore considered to have a larger 'self-cleaning capability'.

Most sewer pipes are either made from reinforced concrete or from PVC. Reinforced concrete and PVC are the preferred materials because of their cost-efficiency, longevity and their advantageous mechanical properties. Depending on the nature of the wastewater some pipes may be built from alternative materials, or be coated with a specialized inner coating in order to prevent corrosion of the sewer pipes. This is more common in industrial sewer systems transporting highly corrosive wastewater. Some sewer pipes will also have an outer coating, most commonly to protect the pipe or rarely as isolation to prevent the dissipation of leftover heat.

Like mentioned above, the cost of a sewer pipe is generally decided by a process of supply and demand. This process has led to a generalized catalogue of sewer pipes in the Netherlands. Some small variation of sewer pipes exists between suppliers, but there is a generalized set of readily available precast sewer pipes with standard dimensions. These readily available pipes will always be cheaper than any custom made pipe, which in turn drives designers to utilize the standardized dimensions within the catalogue for the construction of their sewer systems.

2.4 Introduction to sewer system elements

The function of a sewer system is to transport liquid waste from one area to another. The element facilitating this transport is the sewer pipe.

Wastewater does not consist of only liquids and solvents, however. Within wastewater, large amounts of suspended solids can also be present. Early engineers quickly learned that these suspended solids have the unfortunate tendency to deposit if the right conditions are present. This creates an adequate shear stress from the water onto the inner surface of a sewer pipe and will prevent deposition of solids within the pipes. At the junctions of sewer pipes, where the direction of the flow changes, deposition of solids still tends to take place. Therefore a construction is required to allow access to these junctions to remove undesired deposition of solid material, as well as allow access to the sewer system for inspections. This construction is called the manhole & chamber. The manhole is the access pipe to the chamber, where the chamber facilitates the connection between connected sewer pipes. Chambers without manholes are rare, as access to the sewer system (for maintenance and for inspection) is usually mandated.

Other elements used within sewer systems include:

- Pumps, either to elevate wastewater or to pressurize wastewater.
- Filter elements (like gulley's), to prevent large solids from clogging the sewer pipes.
- Wastewater storage basins, most commonly to store excess storm water during heavy rain.
- Overflow channels, to redirect discharge when the maximum allowed discharge to a treatment plant or surface water body is exceeded.
- Energy sinks, to remove excess kinetic energy from the wastewater.

These will not be further explored within the scope of this report. The pipe and the manhole & chamber together make up for most of the composition of current sewer systems. Therefore the design of these two elements will make up most of a sewer system design and will therefore be explained with more detail in the following chapters.

3. Stakeholder analysis sewer design

3.1 The most common stakeholders

Table 1: List of common stakeholders in a communal sewer design.

Stakeholder	**Description**	**Main stakes**
Client	The organization requesting the design of the sewer system (usually a municipality)	• Required time to design the system • Cost of the design • Cost of the installation of the design
Manager of the new sewer	The organization tasked with managing the designed sewer system (usually the client)	• Cost of maintenance • Availability of the sewer for inspection/maintenance • Reliability of the design • Longevity of the design
Managers of local underground infrastructure	The organizations tasked with managing local underground infrastructure, such as cables and pipes.	• Least possible interference with existing underground infrastructure • Prevention of relocation costs for their underground infrastructure
Local residents	The civilians most likely to experience direct nuisance from the implementation of the new design	• Least possible nuisance • Shortest time disconnected from sewer • Alternative accessibility to their homes
Residents of adjacent discharge areas	The civilians who will perceive indirect nuisance from the implementation of the new design	• Least possible nuisance • Shortest time disconnected from sewer
'Waterschappen'	The water agencies responsible for the connected wastewater treatment plants and most connected surface water bodies	• The type of and concentration of pollutants present in the wastewater • Volume of discharge
Alternative manager of a surface water body	Some larger surface water bodies are managed by different organizations, like Rijkswaterstaat.	• Concentration of pollutants in discharge • Volume of discharge
Road users	All users of the temporarily disconnected roads	• Alternative accessibility to the area
Influential organizations	Large industries, companies or organizations with assets being directly at stake in the project	• Alternative accessibility to the organization • Least amount of interference with the property of the organization
Environmental groups	Local groups of environmental advocates	• Least amount of environmental impact of the implementation of the sewer design

Table 2 gives an overview of the most common stakeholders involved in the (re)design of a sewer system and their main stakes. Note that in most cases, the client will also be the manager of the new sewer system. Table 3 assigns relative weights to these common stakeholders and offers an approach strategy. These given values are merely global estimations, since the true stake and weight of a stakeholder is determined by the location and specific circumstances of a sewer design.

Table 2: Rough estimation of the general stake and weight of stakeholders in a communal sewer design. Includes the advised approach of each of these stakeholders.

Stakeholder	**Stake**	**Weight**	**Approach**
Client	10/10	10/10	Involve directly
Manager sewer	10/10	10/10	Involve directly
Water agencies Managers surface water	8/10	9/10	Consult and inform
Influential organizations	6/10	8/10	Inform and negotiate
Environmental groups	6/10	6/10	Inform and negotiate
Road users	6/10	5/10	Inform and offer alternative accessibility
Local residents	6/10	4/10	Inform
Adjacent residents	5/10	3/10	Inform

The interplay of the different stakes of these stakeholders influences the technical and functional requirements of the sewer design. The client and the manager of the sewer system will determine most of the technical requirements regarding the structural integrity and longevity of the sewer system design. The local and adjacent residents have a stake in the functional requirement of the sewer (as they will bear the consequences of a dysfunctional system). The water agencies and environmental groups will drive the functional and technical requirements relating to protecting the environment (possibility of leakage, pollutants in the discharge to surface water bodies). The water agencies are also usually in charge of the wastewater treatment plants, and therefore have a stake in the maximum discharge - and the concentration of discharge to the wastewater treatment plants. The road users, local residents and local industries have a stake in the accessibility of the local area during the construction phase of the project and therefore determine the planning of the construction.

4. The boundary conditions and functional - and technical requirements of a sewer system

4.1 The boundary conditions

A sewer system can be likened to a river. Neighborhoods function like catchment basins, where sanitary wastewater from households and/or storm water from rain events is gathered and is condensed into either a single or a few discharge streams. Often the discharge from different neighborhoods combine into even larger discharge streams, until the discharge stream is either delivered to a wastewater treatment plant or to a surface water body. By design, neighborhoods therefore function like units. Most commonly, a sewer system is designed either for a single neighborhood or a small set of neighborhoods and then connected to the adjacent system(s). The demarcations of these neighborhood units is decided by the governing agencies, usually municipalities. The location and size of the project area has an important impact on the design of the sewer system, as it both determines the discharge of the system, as well as the connection of the system with adjacent systems.

Sometimes a design is made for only a part of an existing discharge unit. In most cases the sewer for a unit is designed and implemented at the same time, however, and therefore is maintained and replaced at the same time as well.

Either way, the boundary conditions of a sewer design are always provided by the client and form the basis from which all other decisions and calculations are made:

- The street plan of the neighborhood determines the possible progression path of the sewer system.
- The discharge locations determine the direction and location to where the wastewater must be transported.
- The ground level determines the range of elevations where the sewer elements can be placed at each part of the project area.
- The location of the project area and the composition and area of the surface at the project area and/or the number of inhabitant equivalents within the project area determine the functional requirements of the sewer system.
- The conditions and forces acting within the project area determine some of the technical requirements of the sewer system.

4.2 The functional requirements

The functional requirements of the sewer system are mostly determined by the type of wastewater being transported. The two most common types of sewers designed by Witteveen + Bos are the sanitary sewer and the storm sewer. These sewer systems are functionally different in the source of the discharge and where they discharge the waste.

The source of the waste of storm sewers are rain events and the design discharge is determined by rain event models, as shown in chapter 5.2 and appendix .... The storm water is usually discharged into surrounding surface water bodies. The maximum discharge to a surface water body might be limited by its water agency, in which case an alternative emergency discharge location might be a part of the functional requirement of the storm sewer system.

The source of sanitary sewers is urban wastewater from households and offices. The design volume of discharge is determined by inhabitant equivalents, as shown in chapter 5.3. Sanitary sewer water is almost always discharged to a communal wastewater treatment plant. Communal wastewater treatment plants often treat wastewater from large areas. Therefore the discharge location of a sanitary sewer design is often a sewer pipe running towards an adjacent sanitary sewer system. The maximum discharge to a wastewater treatment plant is limited and determined by the agency managing the treatment plant. The maximum discharge to the wastewater treatment plant, and an emergency discharge location are therefore part of the functional requirements of the sanitary sewer.

Combined sewer systems transport both storm water and sanitary waste and therefore have the discharge limitations of a sanitary sewer, while having the discharge requirements of both a sanitary and a storm sewer combined.

Circumstances change over time. Therefore the long term relevance of the design data is important for the longevity of a sewer system. The design data is therefore usually modified with future developments in mind. Design rain events often include an estimated future climate change. The inhabitant equivalents for the design area include projected population increases.

To summarize, the common functional requirement of a sewer system are:

- To transport the wastewater to predetermined discharge locations
- To be able to handle an design discharge, which should remain relevant for the design life time of the system
- To avoid exceeding the maximum discharge to the discharge locations

4.3 The technical requirements

The technical requirements of a sewer system are determined by a combination of demands from the client, the manager of the sewer system and the other stakeholders.

Sewer systems are designed with a certain longevity in mind. The design life time of the sewer system is determined by a combination of the structural integrity of the parts of the sewer system, as well as the long term relevance of the design data used. The structural integrity of the system parts in turn is determined by the yield strength of these system parts compared to the forces acting upon the system part. Apart from the yield strength, fatigue, chemical attack and temperature changes can also cause a deterioration of the structural integrity of a sewer system part. Freezing of the wastewater must always be avoided. All of these different factors give specific technical requirements to the sewer system parts.

Aside from the longevity, the system must also be accessible for inspection and maintenance. Inspection is required to determine the rate of deterioration of the parts of the sewer system and therefore helps optimize the maintenance schedule. Inspections also allow the identification of clogging of the system. Periodical maintenance of sewer parts can be performed through access points without requiring opening of the covering soil and structures (streets). The accessibility of the sewer system therefore also determines certain technical requirements of sewer system parts, namely the addition of manholes to chambers and the maximum distance between manhole & chambers.

Safety is another important requirement. This includes both the safety of the workers installing the sewer system and the safety of inspectors and maintenance personnel. The buildup of dangerous gasses must be prevented. As such some of the technical requirements of a sewer system are derived from safety considerations.

The sewer system must be installed, which requires the digging of ditches. The digging of said ditches must be allowed (streets are owned by municipalities, and therefore the most easily available locations to gain permission to install sewer systems). Obstacles are avoided as much as possible, as the relocation of these obstacles can be problematic (obstacles include underground infrastructures, trees, buildings, statues). And lastly the ditches should be both of sufficient size to be able to install the sewer system elements. The safety requirements for the people working in the ditches were already mentioned previously.

Lastly, clogging of the sewer system should be prevented, which requires a combination of adequate filter elements (gulley's, rosters) and sufficient shear stress at the level of the walls of the sewer pipes to prevent the deposition of suspended solids within the system. Therefore the pipes must have an adequate slope and/or shape.

To summarize, the following technical requirements are common for the design of sewer systems:

- The sewer system has a predetermined design life time
- The sewer system elements have adequate yield strength and protection against existing forces and conditions
- The sewer system elements have an adequate cover to protect against frost and large surface loads
- The sewer system elements must be accessible for periodic inspection and maintenance
- The sewer system elements must be safe to be installed and accessed
- The sewer system elements must be able to be installed
- The sewer pipes must have an adequate slope and/or shape to prevent deposition of suspended solids

A specific technical requirements for sanitary sewers:

- The pipes have a maximum fill rate to avoid anaerobic processes within the sanitary wastewater and the corresponding buildup of dangerous gasses.

5. Methodology

5.1 Design requirements

5.1.1 Pipes

The pipe is the main element in any sewer system. The dimensions of pipes are determined by the width, height and length of the pipe and the thickness of the pipe wall. In case of circular pipes, the width and the height of the pipe are the same as the diameter of the pipe. The width, height, or diameter can either be measured from the inside of the pipe, or the outside of the pipe. The material of the pipe determines the friction coefficient, yield strength and elasticity modulus of the pipe.

When used in a design, the location of pipes is determined by their Cartesian coordinates. In the Netherlands, the Rijksdriehoeksmeting is used as the Cartesian coordinate system. The reference point of this system is the spire of the Onze Lieve Vrouwentoren in Amersfoort (x = 155 000, y = 463 000), chosen for its central location in the Netherlands. The reference point is purposefully not the origin (x = 0, y = 0) in order to prevent negative x or y coordinates when measuring any point in the Netherlands. The y-coordinate is also chosen in such a way that the y-coordinate in any point in the Netherlands is always larger than the x-coordinate.

The reference level of the z-coordinate is the NAP. This was originally determined by the average flood level during summer of the river Het IJ, measured on 1 September in 1683 and 1684 and was called Amsterdams Peil. There have been some recalibrations of this reference level to account for shifts in z-value of the old physical reference points, after which the name changed to Normaal Amsterdams Peil (NAP). There are a number of different reference points, forming a network all over the Netherlands in order to determine the z-value of any given structure.

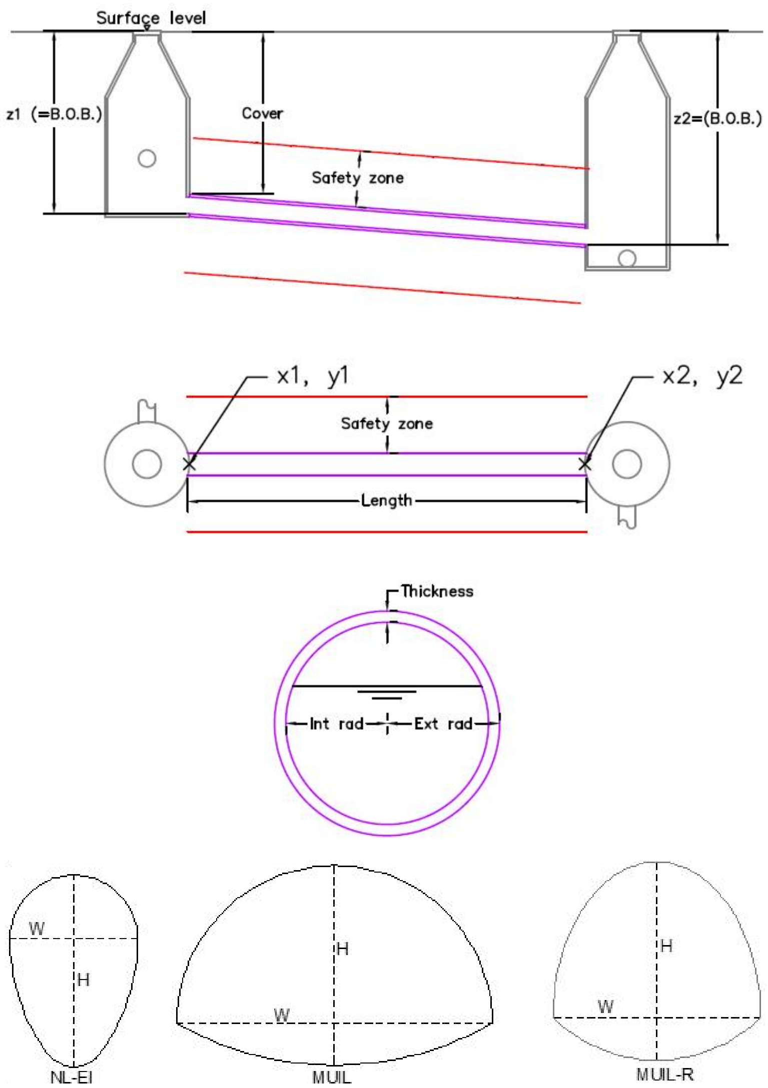
Within a sewer system, the x, y and z value of a manhole & chamber is measured at the center of the top of the structure (center and top of the lid). The x, y and z value of the connection of the pipe with this manhole & chamber is measured in relation to the x, y and z coordinates of the manhole & chamber. The x and y coordinates are recorded by their location within the Rijksdriehoeksmeting, whereas the z-coordinate is recorded by the B.O.B. value, which is calculated using the difference between the z-value of the lid of the manhole & chamber and the z-value of the inside of the bottom of the pipe. Any given pipe will have two sets of x and y values and two B.O.B values, one set at the beginning of the pipe and one set at the end of the pipe.

The slope of the pipe can be determined from the B.O.B values and the length of the pipe. The required slope can be calculated using hydrodynamic formulas, but to save time there is a general rule of thumb for the minimum value of the slope of sewer pipes. For sanitary sewer this value is 1:500 or 0,2%. For storm sewer this value is 1:1000 or 0,1%.

Sewer pipes are subjected to a number of different external forces.

Since freezing of the wastewater running through the sewer pipes can easily crack the pipe, they must be buried at least beneath the level to which frost can penetrate the ground. This depends on the composition of the soil but is usually in the order of 20cm. Most sewer pipes are installed beneath street level for convenience sake. Many municipalities actually have their own technical demands for the design of sewer systems where a minimum cover is stated. The municipality of Rotterdam demands a minimum cover of 1,1 meter for instance.

Existing ground water levels can cause water pressure on sewer pipes. Uneven setting of soil can cause moments and shear forces acting on sewer pipes. The weight of the surrounding soil puts pressure on the walls of the sewer pipes. All of these forces have to be accounted for in order to design a sewer system with longevity. Current precast reinforced concrete pipes have a high yield strength, but sometimes the acting loads are large enough to warrant alternative shapes.



Dimensions:

Internal radius*	[m^1]
External radius*	[m^1]
Thickness	[m^1]
Length	[m^1]

Location:

x_1, y_1, z_1	
x_2, y_2, z_2	
Cover	[m^1]
Safety zone	[m^1]

Hydrodynamics:

Discharge	[m^3/s]
Flow rate	[m^1/s]
Filling rate	[-]
Slope	[-]
Friction coefficient	[-]

External forces:

Traffic load	[kN/m^2]
GW pressure	[N/mm^2]
Specific weight	[kg/m^3]
Setting	[mm^1/y]

Materials:

Elasticity modulus	[N/mm^2]
Yield strength	[N/mm^2]
Pipe roughness	[mm^1]
Relative roughness	[-]
Friction factor	[-]

Figure 1: Explanation of the dimensions of sewer pipes.

As a designer, there should be no consideration for the supplier when designing sewer systems in order to avoid distortion of competition. The general supply of precast sewer pipes determines the desirable dimensions and shape of the sewer pipes, however. Therefore Civil Infra Benelux publishes a general catalogue for circular pipes to use in Civil 3D when designing sewer systems in the Netherlands.

Table 3: Common dimensions of sewer pipes, taken from the CIB catalogue for Civil 3D.

Circular pipes			
Reinforced concrete pipes		**PVC pipes**	
Inner diameter	**Thickness**	**Outer diameter**	**Thickness**
300 mm[1]	55 mm[1]	100 mm[1]	3.5 mm[1]
400 mm[1]	55 mm[1]	110 mm[1]	3.5 mm[1]
500 mm[1]	70 mm[1]	125 mm[1]	3.7 mm[1]
600 mm[1]	85 mm[1]	160 mm[1]	4.7 mm[1]
700 mm[1]	95 mm[1]	200 mm[1]	6.3 mm[1]
800 mm[1]	105 mm[1]	250 mm[1]	7.3 mm[1]
900 mm[1]	110 mm[1]	315 mm[1]	9.2 mm[1]
1000 mm[1]	125 mm[1]	400 mm[1]	11.7 mm[1]
1200 mm[1]	154 mm[1]		
1500 mm[1]	187 mm[1]		

5.1.2 Manhole & chamber

The manhole & chamber is the hinge in the sewer system. Usually manhole & chambers are installed wherever a sewer system changes in direction. Sometimes a manhole & chamber is inserted in a otherwise linear section when the maximum length of the section is exceeded. This maximum length can be determined by the bending resistance of the pipe (long pipes are more prone to prolapsing) or the accessibility regulations for the sewer system (for maintenance and inspection).

Since a manhole allows access to the sewer system, the manhole & chamber is also the location where measurements can be taken of the sewer system. The x and y coordinates of manhole & chambers are taken from the center of the cover. The z coordinate is taken from the rim elevation. The z coordinates of the connecting pipes are determined by measuring the distance from the invert level of the pipe to the rim elevation of the manhole & chamber.

The dimension of a manhole and chamber are determined by the rim to sump height, the length and width of the inside of the chamber, the thickness of the walls and the thickness of the floor. Square chambers are most common in the Netherlands. The manhole & chambers are cast to specification, therefore the location of the connection holes and the rim to sump height are determined by design.

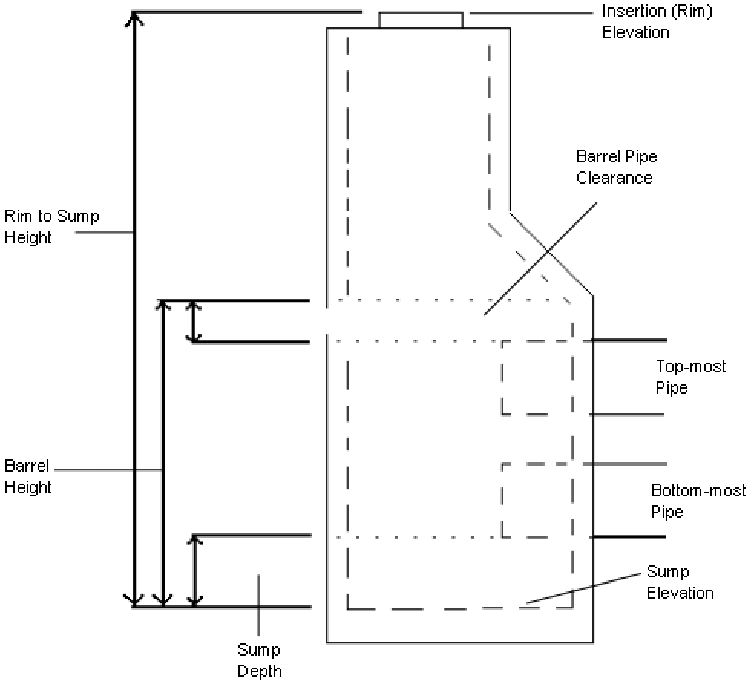


Figure 2: Terminology for the determination of pipe network structures in Civil 3D.

5.1.3 Installation ditch.

Sewer systems are buried underground for sanitary reasons. In order to install or replace a sewer system, a ditch must therefore be dug, and the sewer elements must be installed correctly. The regulations and requirements of the installation of sewer elements are given by the *NEN-EN 1610 + NEN 3218-1* Dutch national version of the corresponding Eurocodes. The safety requirements for working in ditches are given by the Abomafoon 2.06. The dimensions of an installation ditch are determined by the width of the ditch measured at the bottom, the depth of the ditch and the slope of the ditch walls. When a normal ditch slope is not possible due to external constraints, a vertical slope can be used in conjunction with a formwork.

5.2 The common design methodology of a Dutch sewer system

There are four phases in the design of a sewer system, with increasing detail per phase:

- The SO - the first global sketch of the sewer system, used to explain the first idea of the design
- The VO - to determine of the idea fits globally in the design space, avoiding global obstacles
- The DO - the definitive design, includes the final dimensions of the elements of the sewer system, the invert levels of the pipes, cross-sectional profiles of the elements of the sewer system and global cost analysis
- The UO - the implementation design, includes everything required to implement the sewer system including the installation ditches, cross-sections, detailed notifications of the elements of the sewer systems, detailed location of all of the elements, final clash detection with existing infrastructure, phasing of the implementation of the system and precise cost analysis of the entire implementation

The design methodology is therefore very dependent on the type of design drawing requested by the client. It is not always the case that a designer is responsible for the entire progression from sketch to implementation drawing. The following description therefore assumes a natural progression through all of the phases of the design, from sketch to implementation design.

When considering sewer design, usually there are two separate possible sewer systems to design for. Either a sewer system for storm water, or a sewer system for sanitary water. Industrial wastewater (either directly from an industry or from rain water in areas where industrial pollution is likely) usually follows either the design of a sanitary sewer or the design of a storm sewer modified to allow for separate treatment of the wastewater in an industrial wastewater treatment plant. Rainwater near gas stations is diverted to a catchment basin for treatment with an OBAS ('Olie Benzine Afscheider', or 'Oil and Gasoline Separator') instead of being discharged into a local surface water body, for instance.

Sanitary and storm sewer systems have a slightly different design process. In the case of a sanitary sewer system, the discharge points of the system are less variable since the discharge has to reach a treatment plant. In the case of a storm sewer, the system can be discharged in existing water bodies, and therefore the system can have multiple discharge locations. The source and quantity of discharge also differs and is calculated differently. For a sanitary sewer, the average discharge is calculated by counting the number of households and multiplying this with an empirically determined discharge coefficient per household (in Dutch: 'Inwoners Equivalenten' or IE). This average discharge is then multiplied with an empirically determined variation coefficient in order to obtain the peak discharge value. The discharge of a storm sewer is determined through a rain event simulation, utilizing a predetermined reference rainfall event. Usually this is the most critical rainfall event recorded in the last x number of years.

All of the sewer designs start with a global sketch of the design (SO) where a simple alignment of the sewer is drawn, following the basic street plan of the area, using the project boundaries given by the client. This method avoids global clashes with existing structures. Some of the functional requirements of the system can already be globally included in the first sketch, such as the overview location of the drainage points and possibly the location of the storage space of the system. Usually there is still consultation with the client regarding their specific desires for the sewer system during this phase.

When the client agrees with the basic sketch of the sewer system, the final functional and technical requirements are determined. The coordinates and elevations of the pipes and structures are determined. First the peak discharge requirements of the system is calculated, and then discharge in time for each element of the system is calculated. The buffer capacity of the system is determined. Any overflow requirements are determined. Finally, using all this information, the final dimensions of all of the elements of the system are determined. These calculations are usually done using computer software, rather than by hand. When all of this information is calculated, a temporary design drawing (VO) is made of the system, using the obtained dimensions of all of the elements and a clash detection is performed with existing obstacles and underground infrastructure. The main purpose of the temporary design is to observe whether the desired design of the sewer system can be physically implemented within the available design space.

If the client agrees with the temporary design, a definitive design is produced (DO). In the definitive design any final alterations to the temporary design are implemented, the entire system is recalculated and validated in the simulation software and the sewer system elements are finalized, including their coordinates and elevations. Detailed design drawings of the sewer system are made (overview drawings as well as cross-sectional and detail drawings). And finally a global cost estimation for the project is made.

When the final design of the sewer system is approved, an implementation plan is created and the implementation design drawings are made (UO). This includes a phasing of the implementation, an overview drawing of the sewer elements, drawings of the installation ditches and foundation of the sewer elements, if necessary per phase (overview and cross-sectional) and precise drawings of all the elements of the sewer system. The contractor should be able to construct the entire sewer system 'as drawn' based on the information given in the implementation design drawings. A calculation of the total volumetric displacement of soil during construction and a calculation of the required volume of foundation sand are made and a final cost estimation for the entire project is calculated.

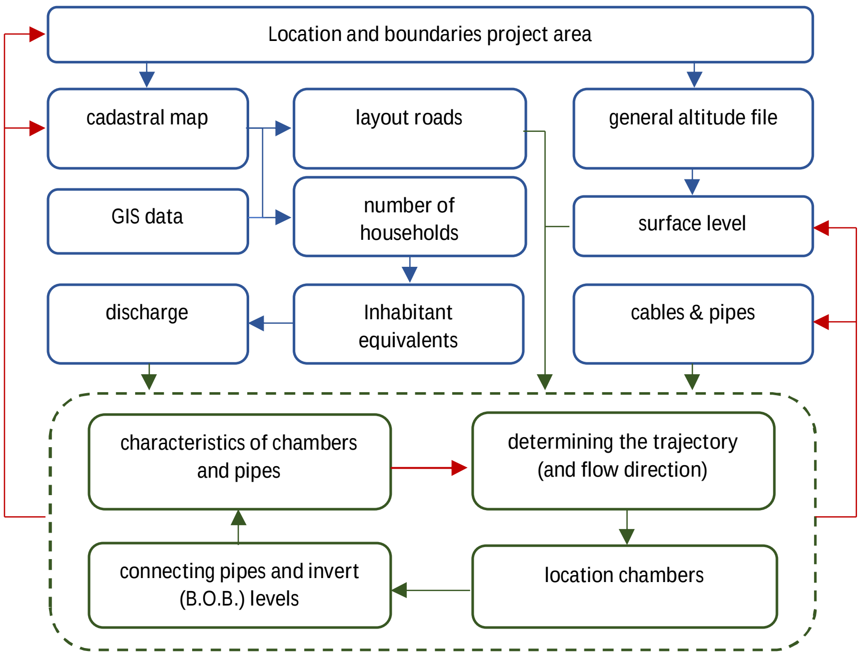


Figure 3: Flowchart of the design process of a temporary design (VO) for a sewer system. In blue the preparatory phase where the current situation and the functional and technical requirements of the sewer system are determined. In green the actual design phase of the sewer system and in red the feedback loops that can occur during the design process.

5.2 The design process in Civil 3D

A design company can be contracted for any single one of the four phases in design. For the following description, it is assumed that all four phases of the design are handled by Witteveen + Bos.

For the sketch phase (SO), a Designer of Witteveen + Bos will typically start by obtaining the first functional and technical requirements from the client, as well as the boundaries of the project. A project map is created using a similar structure as shown in figure 4, with a specific project name. A main design drawing is created in Civil 3Dusing the Witteveen + Bos template. The cadastral map of the project area is imported in Civil 3D and a separate drawing is made with the project boundary, these are saved in their respective locations and imported in the main design drawing using x-referencing. A quick alignment of the desired sewer system is made following the streets detailed in the cadastral map, ending at the requested drainage point coordinates. Any conflict situations with existing objects on the cadastral map are avoided.

The sketched idea for the sewer design is pitched to the client. Any additional functional and technical requirements are determined in consultation with the client. If the client agrees with the idea, the temporary design is started.

For the temporary design (VO), additional information is gathered. An on-site investigation is held in order to observe possible objects and limitations in the design space. The ground level data is gathered, either by consulting the AHN (general altitude data of the Netherlands), requesting recent measurements performed by or commissioned by the client or by commissioning own on-site measurements. If the sewer design coincides with other projects in the area, for instance during the design of an entire new neighborhood, it might be possible that the design ground level ('ontwerpniveau') of said project should be used instead of the existing ground level ('maaiveldhoogte'). A surface of said altitude information is generated in Civil 3D, saved separately and imported into the main design drawing using data referencing. The invert levels of the pipes of the sewer system are determined either starting from the known invert level of the discharging pipe, or from the known invert level of the highest pipe in the system (known from the minimum cover required). If required the alignment of the sewer system from the sketch drawing is adapted according to the new information and the final alignment is exported to the Hydrologist. The Hydrologist will import the alignment into Infoworks and import the relevant data. Through simulations, the dimensions of the sewer system are decided and this information is returned to the designer. The overview drawing of the sewer design (with the correct dimensions for the sewer parts) is created. When the designer is content with the drawing, a second check is performed by a colleague before the drawing is returned to the client.

When the client agrees with the VO, a definitive design is created (DO). The invert levels and cross-sectional views are drawn. Data of the existing underground infrastructure is imported. A three dimensional clash detection is performed. Any alterations to the sewer system design are run through Infoworks again to guarantee the functionality of the final design. The installation ditches are drawn. And finally a global cost estimation is performed. The drawing is checked by a colleague before sendoff.

The implementation design (UO) incorporates the final feedback from the client. A last check of the system is performed if any changes were still required. Then an implementation plan is created. The drawings are created, if necessary for each construction phase. Overview, as well as cross-sectional views and detail views are created. All of the required information is included in the final drawing. The contractor should be able to construct the entire sewer system as drawn.

5.3 Possibilities for improvement of the design process

5.3.1 Improving the exchange of data between Civil 3D and Infoworks

The traditional method used at Witteveen + Bos to draw sewer systems in Civil 3D is to draw traditional (poly)lines. Civil 3D allows designers to draw sewer systems as 3D objects using the Pipe Networks feature. By importing premade parts lists into Civil 3D, a designer can quickly draw three dimensional sewer elements by selecting the elements from said list. The CIB has already created lists of common parts for Dutch sewer systems. Pipe Networks functions similar to a corridor and allows a designer to very quickly create cross sectional views of the sewer system. Since the parts lists are essentially a database for the network parts, a lot of information can be automatically assigned to parts of the sewer system. Pipe Networks has therefore recently become increasingly popular to use as a tool for drawing sewer systems.

Since the method of using Pipe Networks to draw the sewer systems automatically assigns all of the relevant information to each sewer system part, there is a possibility to enhance the speed at which data can be exchanged between Civil 3D and Infoworks. With the traditional drawing method, a lot of information has to be assigned by hand to the sewer system in Infoworks. Almost all of this information is already readily available in the parts lists in Pipe Networks, however. The only difficulty is extracting the information in such a way that it can imported easily into Infoworks.

Recently Dynamo has extended their visual programming tool with a plugin for Civil 3D. This allows for visual programming within Civil 3D using premade Python script blocks. A Dynamo script can therefore be generated in Civil 3D in order to do automate certain existing drawing processes, as well as create possibilities previously not supported in Civil 3D. One of these things is to automatically export data from Civil 3D into .xml and .csv Excel files. File extensions which can directly be imported into Infoworks. Another possibility is to extract data from .xml and .csv files in order to redraw a Pipe Network. File extensions which Infoworks can directly export.

By utilizing a smart Dynamo script, the exchange between Civil 3D and Infoworks can therefore be almost fully automated, saving both the designer and the hydrologist a lot of time. Automated transfer between Civil 3D and Infoworks does already exists, but requires an expensive license from a third party developer, whereas Dynamo does not require an additional license to be used.

5.3.2 Using the corridor functionality to automate the drawing of the installation ditches for sewer systems

The traditional method to draw the installation ditches for Pipe Networks is by offsetting the lines for the sewer elements in the overview drawing, and drawing the cross sections of the ditch manually. Civil 3D allows for easy drawing of objects with continuous cross-sections through the corridor function. A pre-defined cross section can be created in Subassembly Composer, after which this subassembly can be imported in Civil 3D in order to build a corridor with said subassembly as the building block. Subassembly Composer allows the creation of interactive subassemblies, which generate the cross section according to input parameters. By creating a subassembly which follows the Dutch codes regarding installation ditches, the drawing of the installation ditches can be fully automated through the corridor feature. This feature allows for easily generated cross-sectional views, saving the designer a lot of time drawing the installation ditches for the sewer system.

6. Results

6.1 Improving the exchange of data between Civil 3D and Infoworks

In order to improve the data exchange between Civil 3D and Infoworks, the Dynamo plugin in Civil 3D was used. Using the Current Drawing Dynamo node, the database from the current drawing can be extracted. From this database the Pipe Network information is extracted using the PipeNetwork node. From the PipeNetwork node, all of the relevant information of the PipeNetwork parts can be extracted by using the relevant Dynamo nodes.

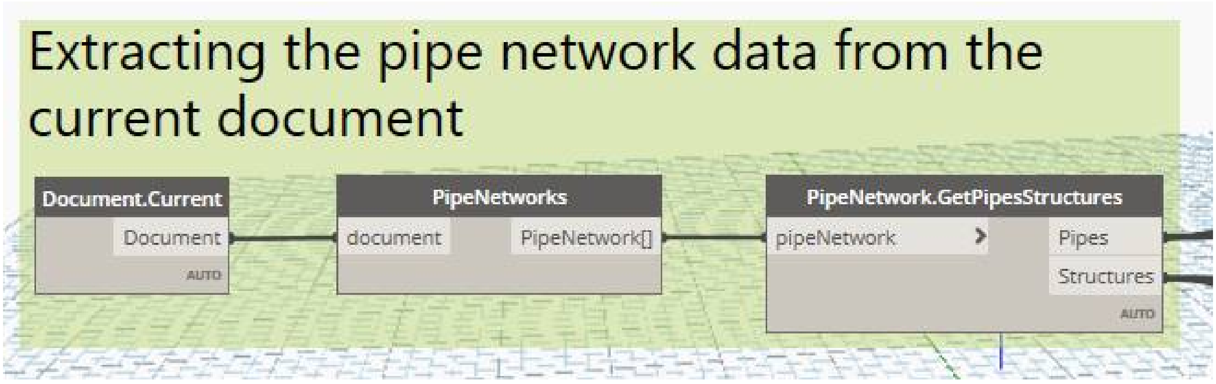


Figure 4: Extracting the pipe network from the current document.

In order to make importing the data from Civil 3D into Infoworks efficient, the data has to be structured in a particular way. The easiest transfer of data would be through either an .xlsl or an .csv file. For the pipes of the sewer system the upstream node (us_node_id), the downstream node (ds_node_id), the name of the pipe (conduit_id), the shape of the pipe (shape), the dimensions of the pipe (conduit_width; conduit_height) and finally the invert levels (us_invert; ds_invert) are required. In order for Infoworks to read the exported data correctly, said information must be structured such that all information of a single pipe is given in the same row of the Excel or Comma Separated Values file. The same is true for the structures, except that the required information for the structures is the name of the structure (node_id), the dimension of the structure (floor_area; chamber_floor), the name of the network the structure is a part of (asset_id) and the location of the structure (x; y; insertion_elevation).

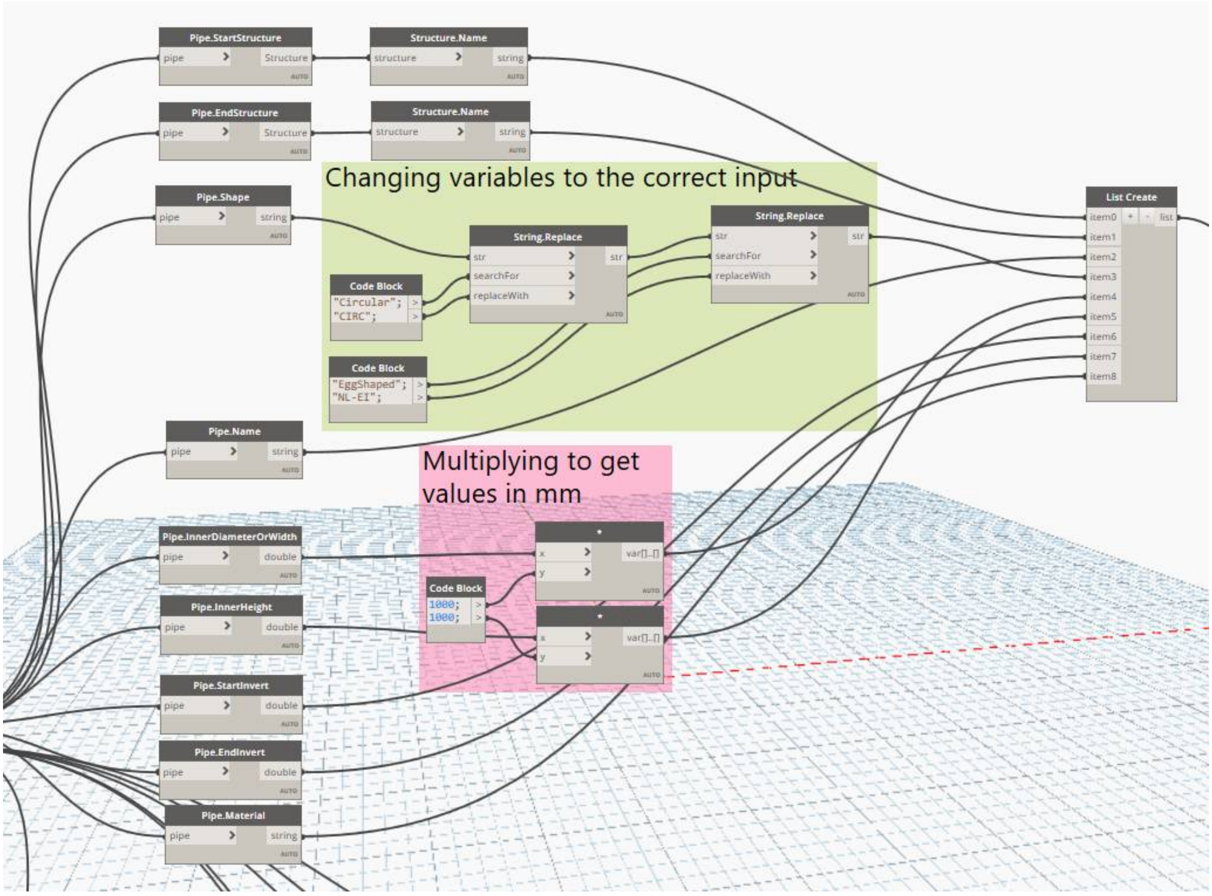


Figure 5: Extracting the relevant information of the pipes and creating a list of this information.

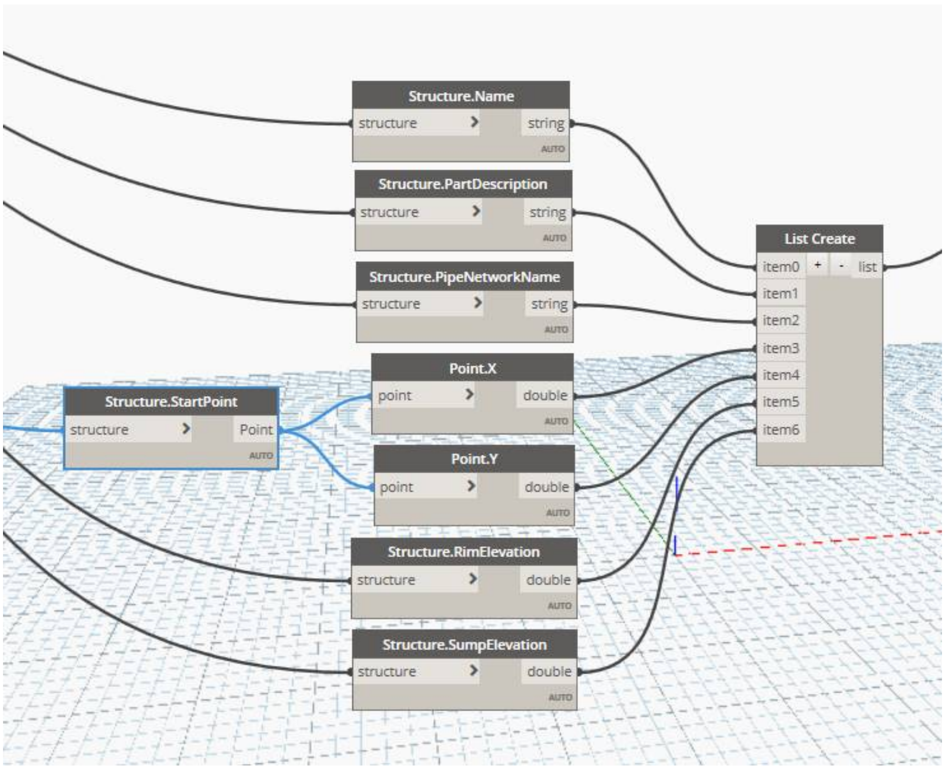


Figure 6: Extracting the relevant information of the structures and creating a list of this information.

The different lists generated by the nodes extracting the relevant information therefore have to be combined into a single list for all of the pipes, and a single list for all of the structures. Once the final list is generated correctly, the lists are exported to a pre-saved empty .xlsl file and a pre-saved empty .csv file for both the pipes and for the structures. The dynamo script prompts a selection of the files before running. The files can be saved in a predetermined shared map, allowing the Hydrologist quick access to the exported data.

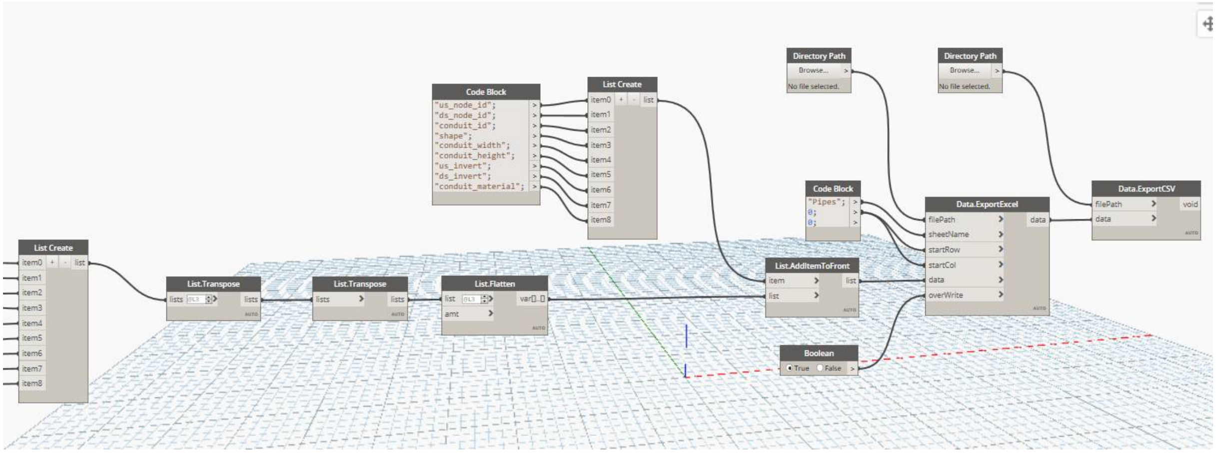


Figure 7: Transposing the list until it groups the information of each pipe in a row, then adding the headings of the information in the correct location. Finally exporting the created table of pipe information in an .xlsl file and in an .csv file.

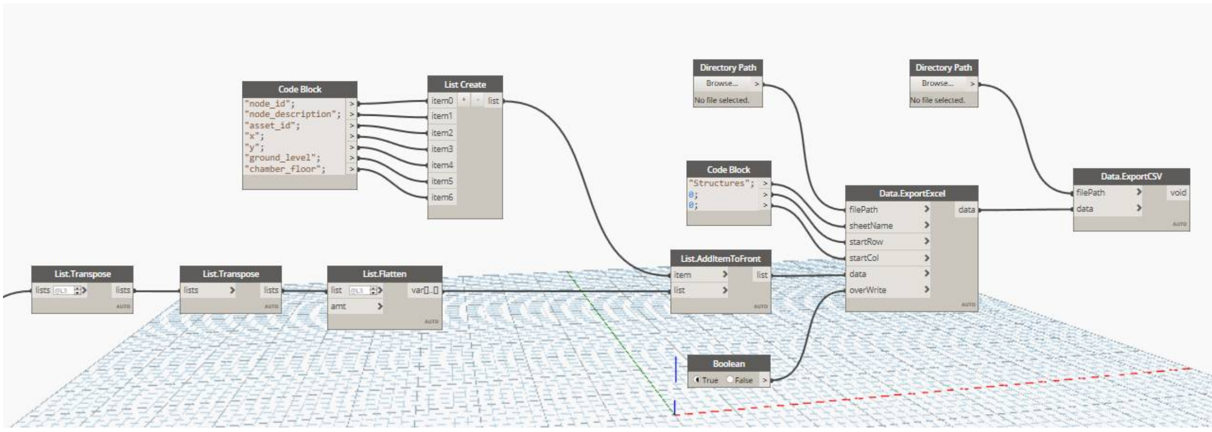


Figure 8: Repeating the same step as in figure 7 for the information of the structures.

Using the dynamo script the export of the required data from the first sketch of the sewer system can be done within a minute.

6.2 Using the corridor functionality to automate the drawing of the installation ditches for a sewer system

The design regulations of ditches for sewer systems are given by the *NEN-EN 1610 + NEN 3218-1* Dutch national version of the corresponding Eurocodes. The *NEN-EN 1610 + NEN 3218-1* does not state the values for all the required parameters though. The support angle 2α of the pipes was taken from *CUR-rapport 122, Buizen in de grond.* The slope angle β was taken from the Dutch safety recommendations for working in ditches, recounted in the *Abomafoon 2.06*. The standardized values for soil characteristics were taken from *NEN 9997-1 + C2:2017.*

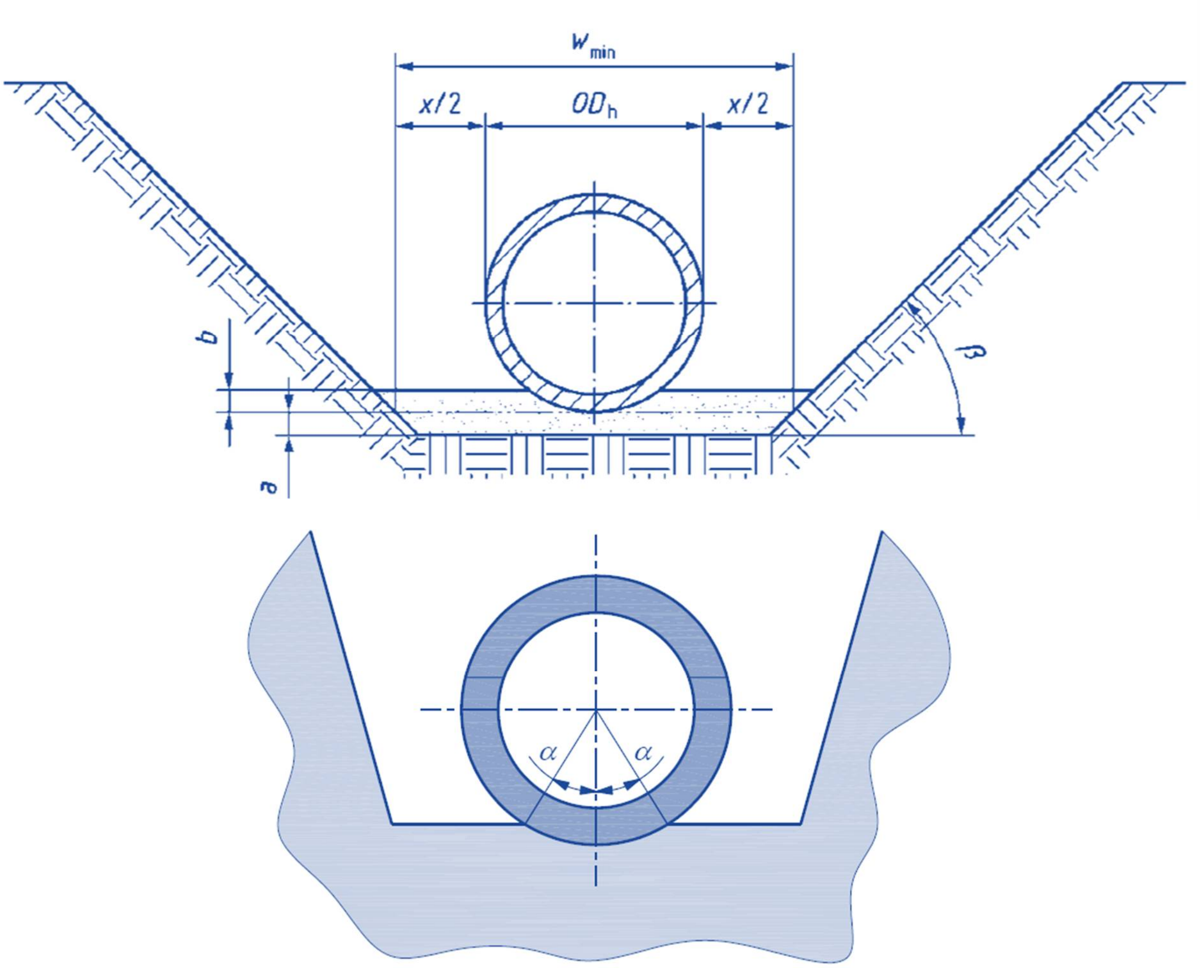


Figure 9: Layout of an open ditch for sewer systems; figure 2 and figure G.1 of the NEN-EN 1610 + NEN 3218-1.

As shown in figure 1, there are five input values required to generate a ditch for a sewer system, namely: the support angle (2α), the height of the soil improvement (h=a+b), the outer diameter of the sewer pipe (OD_h), the extra width (x) and the slope angle (β). Not mentioned in the Eurocodes is a sixth value required to automatically draw the ditch in Civil3D, namely the origin point. The inside of the bottom of the pipe (b.o.b.) is the standardized reference point for pipes in the Netherlands and will be used as the origin.

On the other hand, the values available to the engineer when drawing their sewer system are: the inside diameter of the pipe (Di), the thickness of the pipe (T), the location of the pipe (x,y,z) and the local soil composition as observed from a soil sample. The latter is usually presented according to the soil compositions as mentioned in table 4.

Table 4: Standardized soil types, taken from table 2.1 of the NEN 9997-1 + C2:2017.

Soil type		
Main composition	**Admixture**	**Consistency**
Sand	Clean	Loose
		Moderate
		Fixed
	Somewhat salty , clayey	-
	Very salty , clayey	-
Clay	Clean	Loose
		Moderate
		Fixed
	Somewhat sandy	Loose
		Moderate
		Fixed
	Very sandy	-
	Organic	Loose
		Moderate

The support angle is mentioned in the *NEN-EN 1610 + NEN 3218-1*, but not given. Therefore *CUR-rapport 122, Buizen in de grond* was consulted for the value. This report states 2α both as a simplified value based solely on the soil composition, and as a more accurate value based on soil composition, soil coverage and pipe diameter. Since the purpose of this investigation is to automatically generate a ditch for a sewer pipe, as opposed to actually calculating the internal forces in the pipe, the choice was made to use the simplified values for 2α.

Table 5: Simplified support angles based on soil composition, taken from table 22 of CUR-rapport 122, Buizen in de grond.

Soil Type	2α
Non- or little cohesive soil	30°
Cohesive composed soil	30°
Cohesive soil	45°

Chapter 6.5 of *CUR-rapport 122, Buizen in de grond* explains how these three soil types relate to the standardized soil compositions as stated in table 4.

The slope angle β is also mentioned, but not given in the Eurocode. The code states that the slope angle should be generated from stability calculations. For the purpose of this investigation, stability calculations are too complex to integrate into an automated design. Therefore the slope angles were taken from the Dutch health and safety guidelines for working in ditches. Usually the values stated by the safety guidelines are safer than those generated by stability calculations, unless large surface loads exist in the proximity of the ditch. A rule of thumb is to allow for a 45° angle for surface loads to transfer down into the subsurface soil layers in order to maintain the macro stability of the slopes of the ditch.

Table 6: Maximum slopes depending on soil type and depth of the ditch, as taken from the Abomafoon 2.06.

Soil Type		**Depth (m[1] below ground level)**	**Slope less than: height : width**
Sand or Loam	fixed / undisturbed	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	3,00 : 1,00 1,50 : 1,00 1,25 : 1,00
	loose / disturbed	1,0 - 4,0	1,00 : 1,00
Clay	very fixed / undisturbed	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	perpendicular 2,00 : 1,00 1,25 : 1,00
	fixed / undisturbed	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	perpendicular 1,50 : 1,00 1,00 : 1,00
	loose / disturbed	1,0 - 1,5	1,50 : 1,00

Table 7: Combination of tables 1-3, $\beta = tan^{-1}(h/w)$ *rounded down.*

Soil type					
Main	**Admixture**	**Consistency**	**Depth**	**β**	**2α**
Sand	Clean	Loose	1,0 - 4,0	45,0°	30°
		Moderate	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	71,5° 56,3° 51,3°	
		Fixed	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	71,5° 56,3° 51,3°	
	Somewhat salty, clayey	-	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	71,5° 56,3° 51,3°	30°
	Very salty , clayey	-	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	71,5° 56,3° 45,0°	
Clay	Clean	Loose	1,0 - 1,5	56,3°	45°
		Moderate	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	90,0° 56,3° 45,0°	
		Fixed	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	90,0° 63,4° 51,3°	
	Somewhat sandy	Loose	1,0 - 1,5	56,3°	30°
		Moderate	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	90,0° 56,3° 45,0°	
		Fixed	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	90,0° 63,4° 51,3°	
	Very sandy	-	1,0 - 1,5 1,5 - 2,5 2,5 - 4,0	71,5° 56,3° 45,0°	30°
	Organic	Loose	1,0 - 1,5	56,3°	30°
		Moderate	1,0 - 1,5	56,3°	

The last two required values (x and h) can be found in the Eurocode and are presented in the following tables. The recommended value of x in the Netherlands is always 1 meter, because of the dimensions of commonly used equipment to install, remove or repair pipes. The given values are therefore the minimum values according to the Eurocodes.

Table 8: Determining the minimum width of the ditch, taken from tables 1 and 2 of NEN-EN 1610 + NEN 3218-1.

Outer diameter pipe	**Minimal width of the ditch (OD_h + x)**		
	Reinforced ditch	**Non-reinforced ditch**	
		β > 60°	**β ≤ 60°**
≤ 225	OD_h + 0,40	OD_h + 0,40*	OD_h + 0,40*
> 225 to ≤ 350	OD_h + 0,50	OD_h + 0,50*	OD_h + 0,40*
> 350 to ≤ 700	OD_h + 0,70	OD_h + 0,70*	OD_h + 0,40*
> 700 to ≤ 1200	OD_h + 0,85	OD_h + 0,85*	OD_h + 0,40*
> 1200	OD_h + 1,00	OD_h + 1,00*	OD_h + 0,40*
It's advised to use OD_h +1,00 in the Netherlands. *Compare values of non-reinforced ditch with the values mentioned below (choose greatest).*			
Ditch depth	**Minimal ditch width**		
< 1,00	NA		
≥ 1,00 ≤ 1,75	0,80		
> 1,75 ≤ 4,00	0,90		
> 4,00	1,00		

Table 9: Determination of the minimum soil enhancement h (= a + b), taken from table H.1 of NEN 3218-1.

OD_h (mm^1)		**h (m^1)**
>	**≤**	
-	500	0,15
500	900	0,25
900	-	0,30
The Eurocode includes a classification OD_h ≤ 300 mm, for which h = 0,10 m. However the support angles given by table 2 are only applicable for h ≥ 0,15 m.		

The corridor functionality within Civil3D will be used to automatically generate ditches for a sewer system. Before a corridor can be build, a correct subassembly must be designed in Subassembly Composer.

The Cartesian coordinates (x,y,z) are provided through the selection of the alignment of the corridor and are therefore not required as input parameters. This leaves the inner diameter (Di) and the thickness (T) of the sewer pipes, as well as the soil composition at the location of the foundation of the pipe (GrondBuis) and the weakest soil composition present within the slope of the ditch (GrondTalud). For both of the soil compositions, an enumerator called Grondtype was created. This enumerator includes all fourteen possible soil types shown in table 7. Side is a required input parameter in Subassembly Composer but is set to None in this subassembly, since the ditch will be generated as a whole unit.

Input/Output Parameters					
Name	Type	Direction	Default Value	DisplayName	Description
Side	Side	Input	None		
IDh	Double	Input	400	Binnendiameter	Binnendiameter van de sanitaire rioolpijp.
T	Double	Input	55	Dikte	Dikte van de sanitaire rioolpijp.
GrondBuis	Grondtype	Input	ZSL	Grondtype opleg	Grondtype op niveau van oplegging van de buis.
GrondTalud	Grondtype	Input	ZSL	Grondtype talud	Doorslaggevend grondtype voor talud.
TBek	Double	Input	50	Dikte bekisting	Dikte van de bekisting in mm.

Figure 10: Input parameters

Define Enumeration

Enum Group
Grondtype
CreateEnumGroup

Enum Item	Display Name (Shows in Civil3D)
ZSL	Zand [schoon - los]
ZSM	Zand [schoon - matig]
ZSV	Zand [schoon - vast]
ZZ	Zand [zwak ziltig, kleiig]
ZS	Zand [sterk ziltig, kleiig]
KSS	Klei [schoon - slap]
KSM	Klei [schoon - matig]
KSV	Klei [schoon - vast]
KZS	Klei [zwak zandig - slap]
KZM	Klei [zwak zandig - matig]
KZV	Klei [zwak zandig - vast]
KSZ	Klei [sterk zandig]
KOS	Klei [organisch - slap]
KOM	Klei [organisch - matig]
CreateEnumItem	

OK Cancel Help

Figure 11: The enumeration of the different possible soil types

Next, to make the subassembly dynamic, some target parameters must be defined, in this case the existing surface (EG), which is set as a surface parameter (horizontal) as well as two object parameters named ObjectR and ObjectL, which are set as offset (vertical) parameters.

Target Parameters				
Name	Type	Preview Value	DisplayName	Enabled In Previ
EG	Surface	2	Existing Ground	☑
ObjectR	Offset	2,434	Object right side	☑
ObjectL	Offset	-2,35	Object left side	☑
Create parameter				

Figure 12: Target parameters

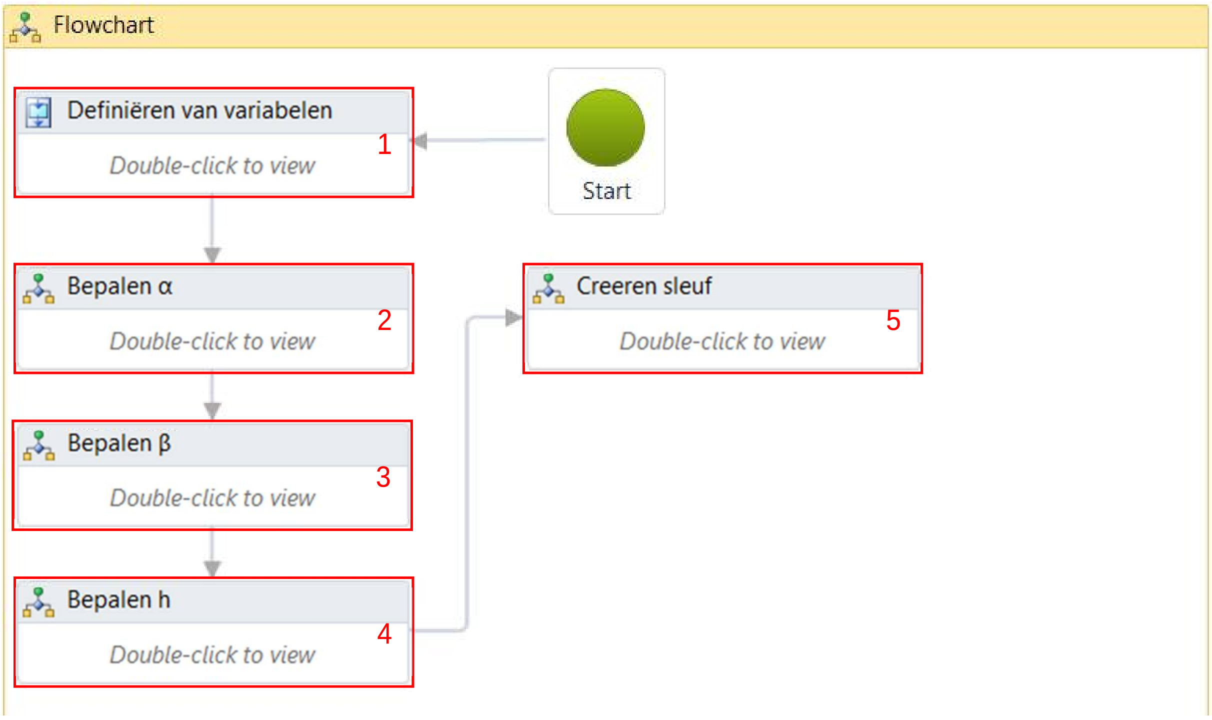


Figure 13: The main flowchart of the subassembly

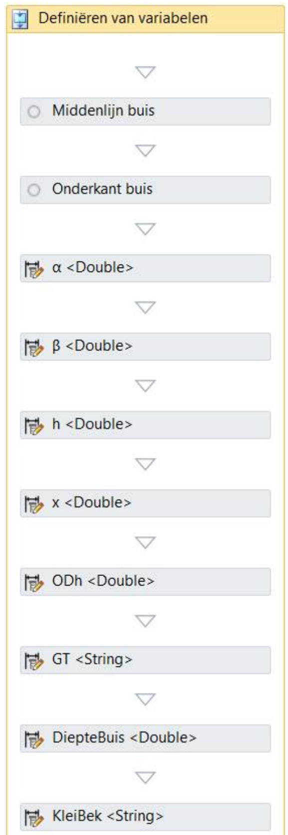


Figure 14: Drawing the center of the pipe and the bottom of the pipe and defining the required variables for the following calculations

Aside from the input parameters, some variables must be defined in order to calculate the geometry of the ditch. This happens in the first sequence (1) of the main flowchart as shown in figure 13. First three auxilliary points are immediately drawn, since these points are directly determined by the input parameters. Then six doubles and two string are defined as variables, some of which are directly determined as well. The variables are shown in figure 14.

After the variables are determined, first the alpha value of the ditch is determined (2) (see figure 9 and table 7) using the input parameter GrondBuis.

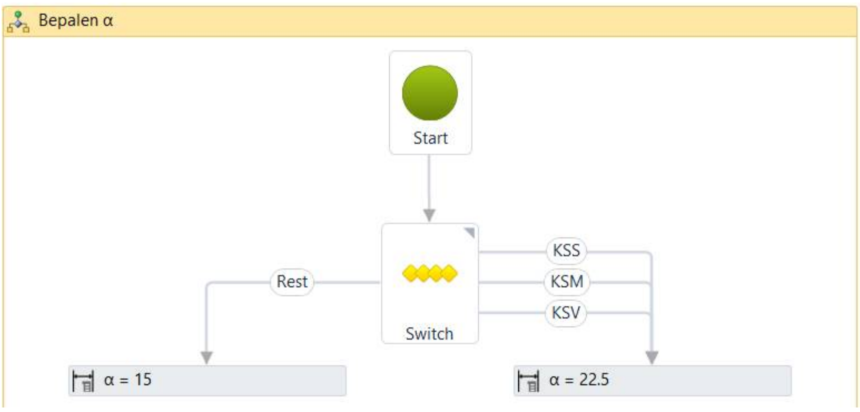


Figure 15: Determining the value for alpha in degrees.

Then the value for beta is generated from the input variable GrondTalud (3). The flowchart of (3) is shown in figure 16. First the possible soil types are split between sand and clay types by making the first decision based on a substring of the string GT defined earlier (shown in figure 14). Then each of the sand types and each of the clay types is split by Switch nodes in order to select the correct soil types based on the input variable GrondTalud. Depending on the depth of the pipe, a value for beta is assigned.

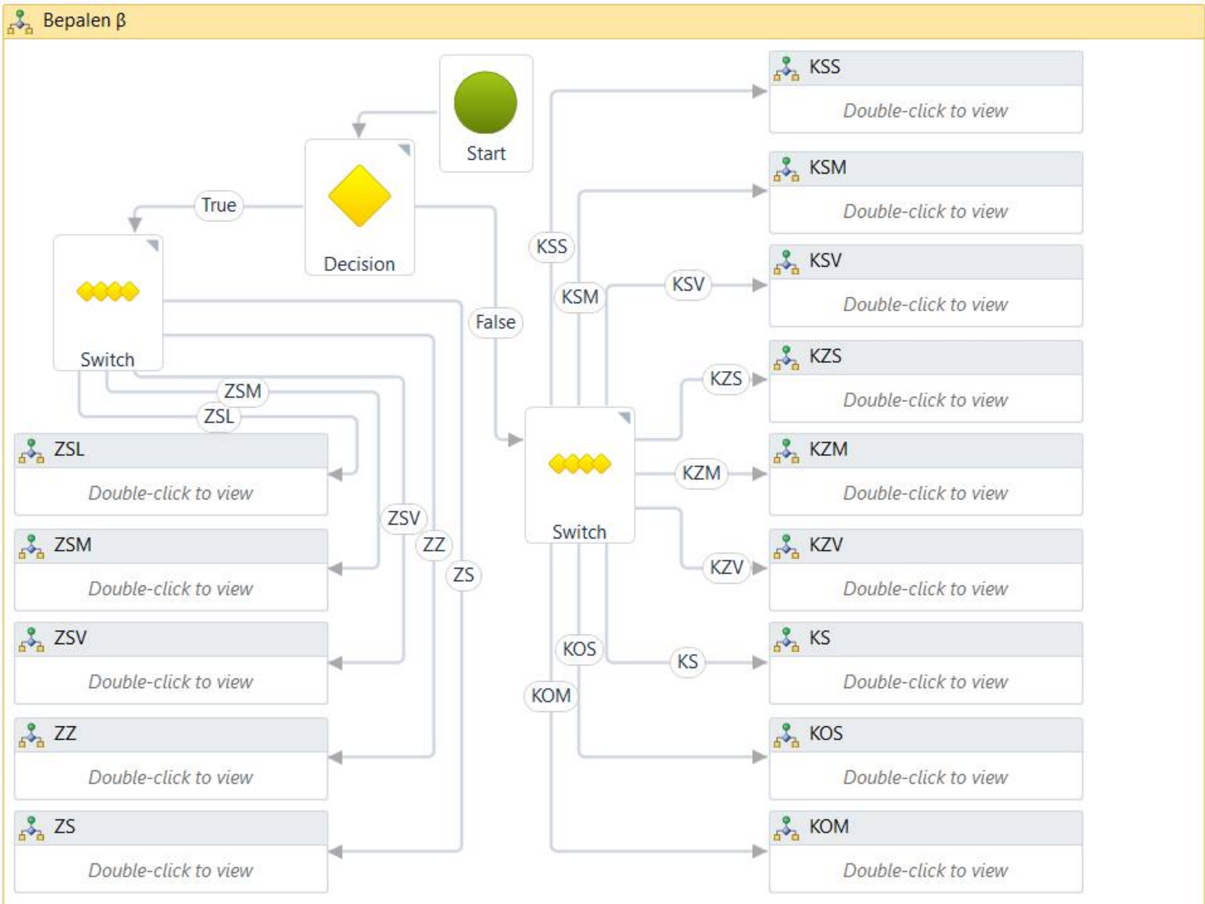


Figure 16: Determining the value for beta

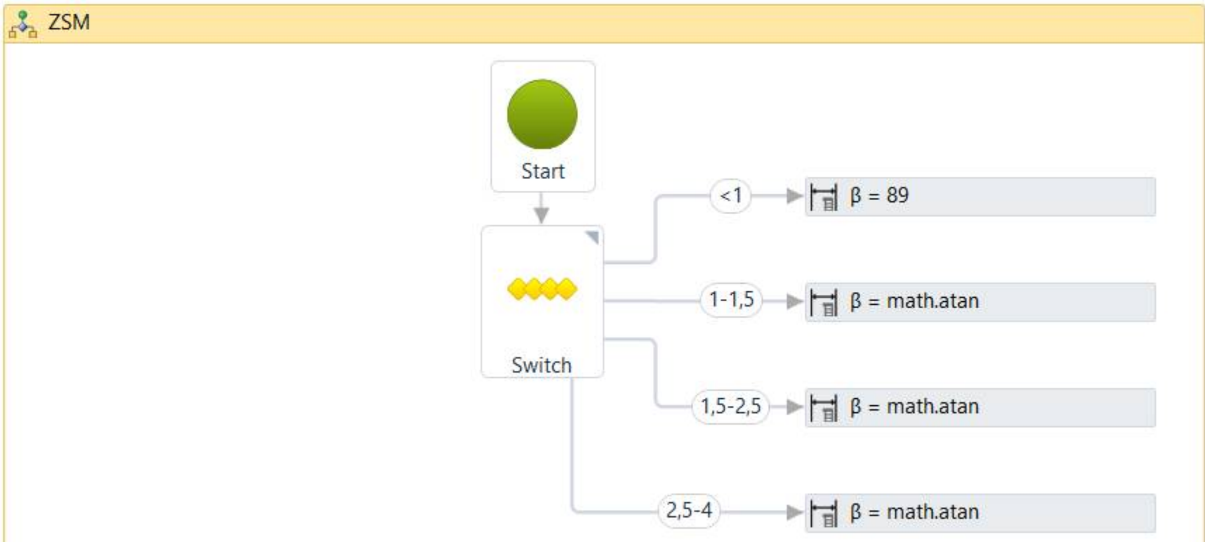


Figure 17: Example of how the value of beta is assigned based on the soil type from GrondTalud and the depth of the pipe (DiepteBuis, calculated in step (1)). See table 7 for the values of beta.

Then the value for h is determined (4), which is the height of the required foundation soil, written in table 9.

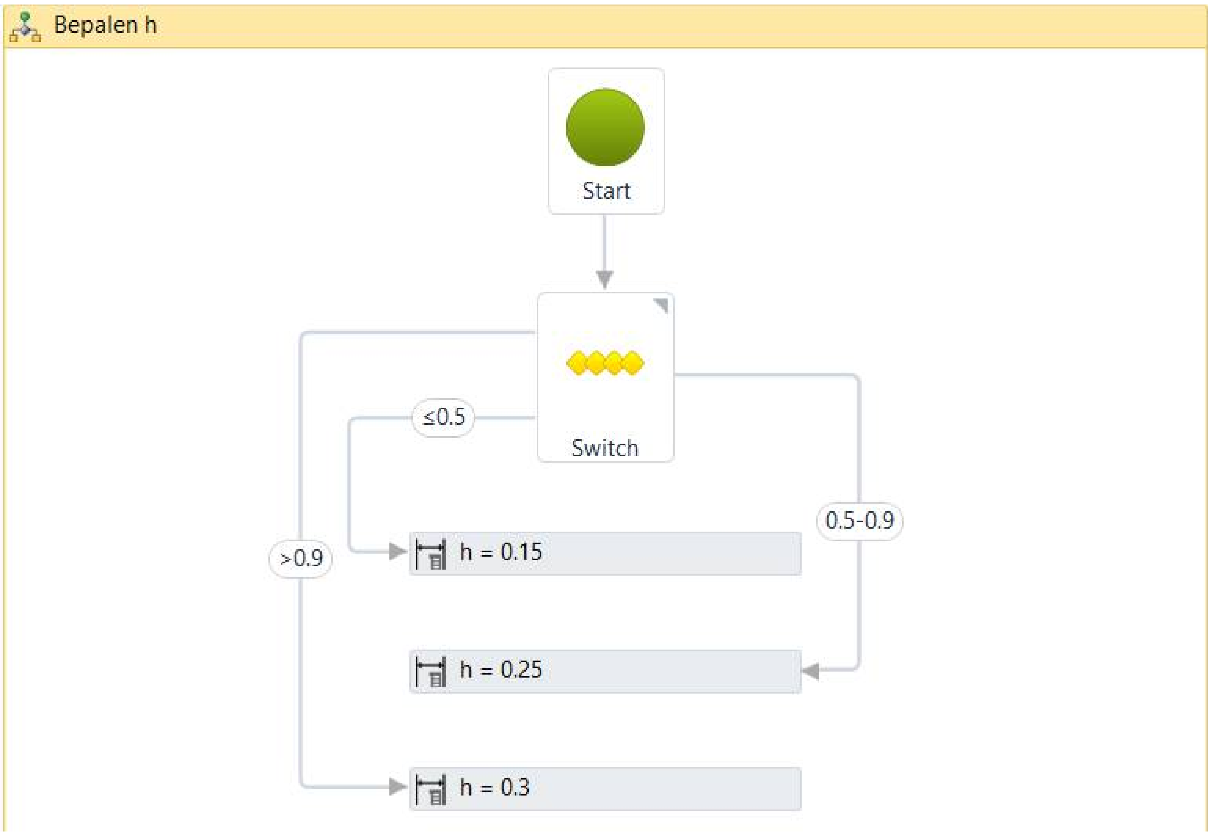


Figure 18: Determining the value of h based on the outer diameter of the pipe (ODh).

And finally, when all the required input data is determined, the ditch itself is drawn accordingly (5). First some test points are set in order to be able to make decisions regarding the offset parameters ObjectL and ObjectR. Then the three decisions in the upper right corner of figure 19 exist in order to test wether ObjectL and/or ObjectR are assigned. This must be done in the case where no objects are assigned in Civil 3D, such that a ditch is still drawn even if ObjectR and/or ObjectL do not exist. All of the other decisions an switches exist to determine if formwork is required in the ditch. The ditch is either drawn with slopes or with formwork. If a ditch can not be drawn due to the proximity of ObjectR or ObjectL, an error message is returned instead.

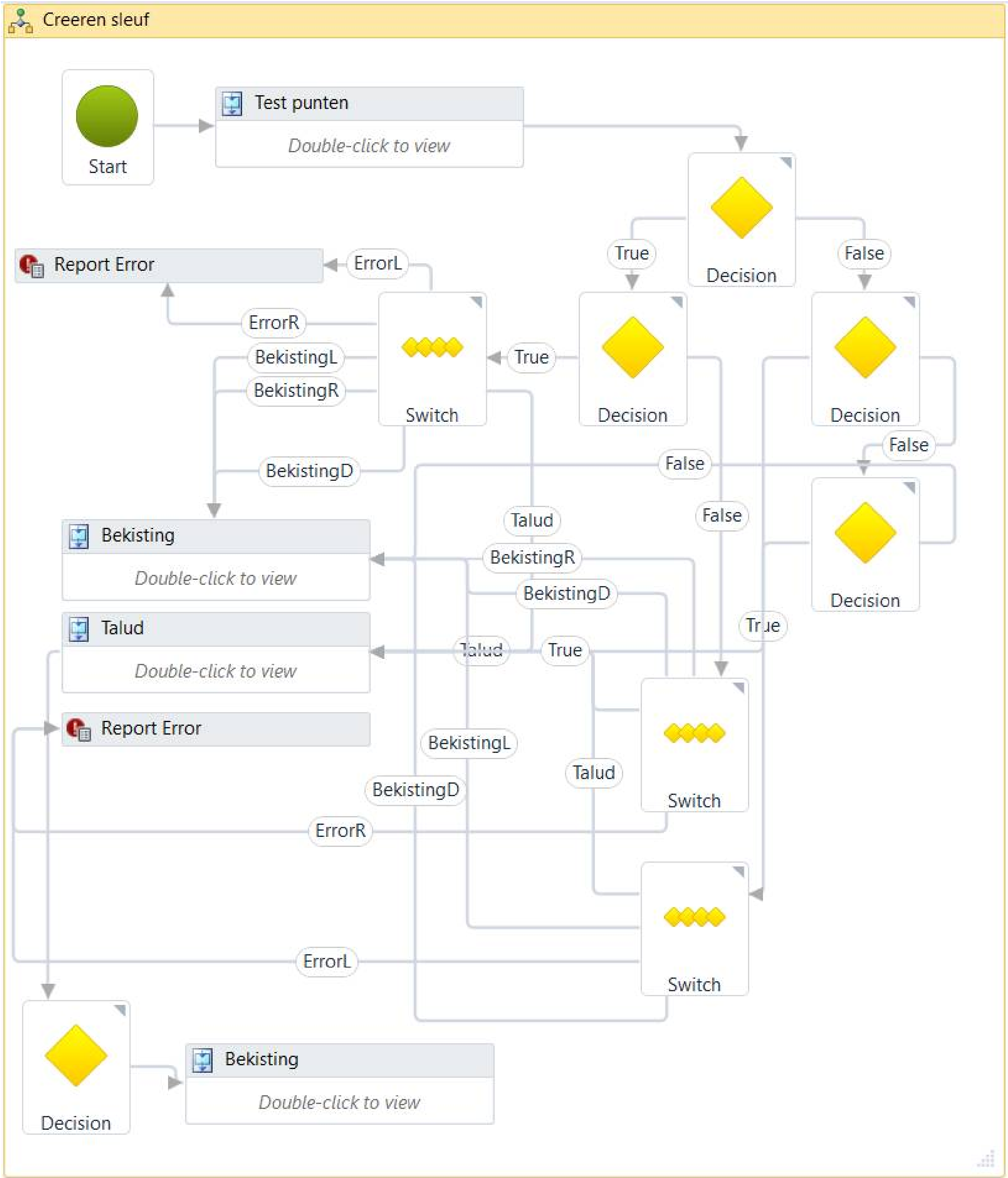


Figure 19: The final generation of the ditch.

7. Recommendations

8. Literature list

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CUR-rapport 122, Buizen in de grond