Parking Garage
Kop van Boulevard

FINAL REPORT

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Note for the teachers

Because our fifth group member Teun quit the Civil Engineering program, the requirements for the Structural Design and Finance part are changed for us.

- **Finance:** the sensitivity analysis should only include an assessment of the effects of a lower/higher discount rate on the net present value. The final proposal can be omitted from the report.
- **Structural Design:** for the Structural Design only calculations of sheet piles, forces of beams and how to withstand the water are conducted.

Summary

The municipality of Enschede wants to redevelop the urban area at the Kop van Boulevard. Housing will be improved by building 500 new apartments. Beneath the apartments a new parking garage will be constructed for residents and shop owners. Next to the parking spaces in the parking garage, it consists also of storage units. As a design firm, the System Engineering process will be use to design the parking garage.

Next to the System Engineering process, a mechanical design is made where loads and forces of the construction are calculated. Therefore, first the load on top of the parking garage is calculated and with those values the calculations for the construction itself could be conducted.

An important part of designing a new parking garage is that circular economy and sustainability (C&S) principles will be used. C&S focusses on use of energy and the re-use of complete objects, parts of objects or materials of objects that will be used in a building. For the new parking garage it is required that circular principles will be applied on two sub-objects of the system.

To check whether the parking garage is financially feasible, a financial analysis is made. In the cash flow overview a time span of 15 years is taken into account for which the cash inflow and outflow are determined. When net cashflows are clear, financial assessments could be conducted with the net present value (NPV), internal rate of return (IRR) and the payback period. The last part of the financial analysis consists of a sensitivity analysis where changes in the discount rate are taken into account.

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1. Introduction

The municipality of Enschede wants to renew the city, enhance the attractiveness of the city and improve housing. Therefore the Kop van Boulevard, an area of three hectare on the west side of Enschede, will be redeveloped. The current area is shown in *Figure 1*. For the redeveloping there will be more space created for housing by building about 500 apartments for different target groups. Besides, there will be room for commercial activities to make it also more attractive for visitors of Enschede.

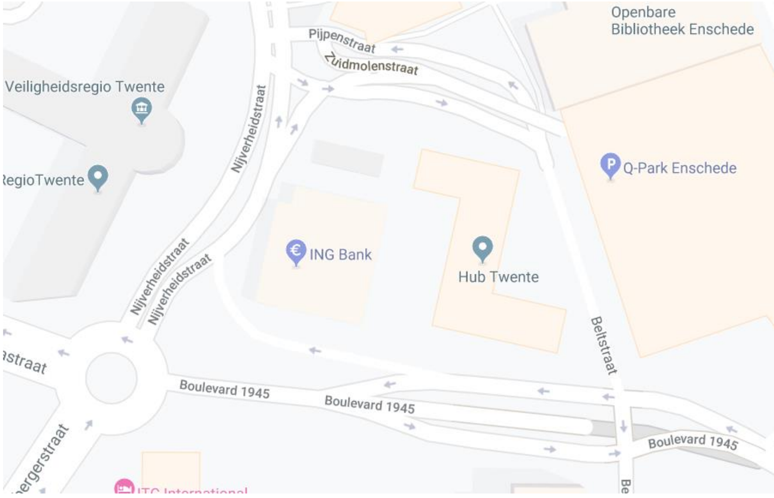

Figure 1: Current Kop van Boulevard area (Google Maps)

Below the apartments, a new parking garage has to be realised. The parking garage should consist of at least 245 parking spaces and storage units for 331 apartments. It is a private parking garage for apartments and shop owners in the area of the Kop van Boulevard. Shop visitors should park their car somewhere else, for example in the Van Heekgarage.

As a design firm, the municipality has asked us to design the parking garage. For the design process the System Engineering method has to be used up to the level of a draft design. In the design circular principles should be included in two sub-objects of the parking garage. Besides, a structural design is required where construction calculations are conducted. The municipality want to know if the project is feasible and therefore a financial analysis is also necessary.

The report is structured in the following way. First the design process will be explained, according to the System Engineering method. Before going into detail about the design, the method itself will be introduced with a short elaboration about the experiences of the iteration loops. Then the project area will be described in more detail with an analyse of the environment and a stakeholder analysis. Next the three main steps will be elaborated, namely the requirements analysis, functional analysis & allocation, design synthesis and finally the verification and validation.

After the design process, the structural design of the parking garage will be discussed and the Circular Economy & Sustainability principles will be introduced. Furthermore, the financial analysis will of the parking garage will be introduced. Finally, a discussion and conclusion are implemented in the report.

2. Method Systems Engineering

In this report an underground parking area is going to be designed. This is not going to be done on the conventual way, but with using a new method. The method that is going to be used is called Systems Engineering (SE). Systems Engineering is an interdisciplinary approach to successfully design systems.

There are multiple reasons why SE is going to be used. The first reason is that the method reduced the number of redesigns. The conventual way of designing is focused more on the design than the requirements for the design. This causes that sometimes requirements are overlooked or new requirements were made later when some parts of the design were already made. This will cause that the design has to be modified which will cost time and money. SE is a requirements-based method. Its goal is by using proper requirements management before the design wherefore less redesigns have to be made. The second reason is that SE is taking into account all the interest of the different parties involved, called stakeholders, to make sure that the design satisfies all the demands of these stakeholders and not only the desires of the client. This is done by focussing on all the wishes and demands of the involved stakeholders and finding the corresponding requirements. Lastly, SE gives more transparency in the design process. This is done by writing down the demands and making a clear connection between the requirements and the demands.

Systems Engineering uses the process model shown in *Figure 2.* The first step that has been taken in the project is finding input. In this step the ambitions and objectives have been formulated by the project team. After this the scope of the system have been found and their connection with the environment. Here taken into account is legislation, documentation and the policy of the municipality. Finally, a stakeholder analysis has been made to find which parties are actually involved in the project, what their views are on the project and how they will be influenced by the project. After this it has been found how much power the stakeholders have and the interest, they have in the project to make a power-interest grid. (de Graaf & van den Berg, 2019)

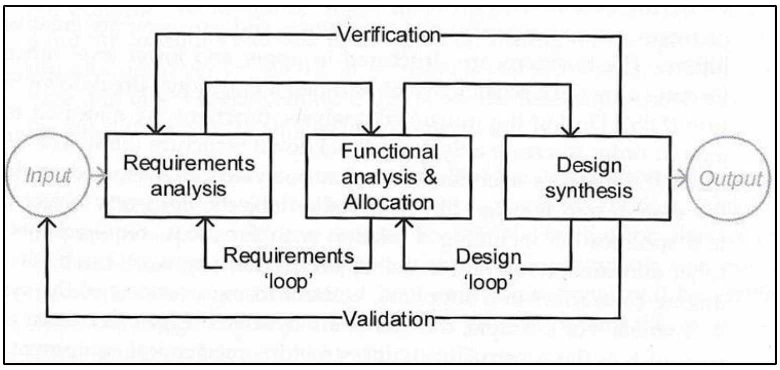

Figure 2: Systems Engineering process model (Handbook SE)

The next phase in the SE process is the requirements analysis. What firstly has been done in this phase is alter the wishes, conditions and expectations of the stakeholders found in the input into SMART requirements. SMART stands for specific, measurable, acceptable, realistic and time-bound requirements. Hereafter requirements have been found which were not put forward by the stakeholders, but are nevertheless important. All the found requirements were taken together in a well-arranged table called the design brief (DB). (de Graaf & van den Berg, 2019)

Firstly, done in the functional analysis and allocation step was determining the system's functionality. This has been done by making a Functional Analysis System Technique (FAST) diagram. The FAST diagram is a model of what the system should do. All function in the FAST diagram were described with a verb and a noun, for example: store cars. Functions do not describe solutions yet. These solutions are described by the object tree.

The loop between the requirements analysis and the functional analysis and allocation is called the requirements loop. This loop is an ongoing process for making new functions for new found requirements. This has been assisted by a Requirements Allocation Sheet (RAS) diagram, which will help to find if there is a corresponding function and object for each requirement. A requirement without function or object is useless, and the other way around.

After this a design has been made in the design synthesis step of the SE process. All objects found in the functional analysis and allocation have to be integrated into the design. This will later be checked with the verification step. There were different designs. These designs were compared to each other in the Multi-Criteria Analysis (MCA). The best design resulting this has been cooperated further. The loop between the functional analysis and allocation and the design synthesis is called the design loop. This loop has made sure that new found objects were taken into the design.

The last step in the SE process is the verification and validation step. The verification makes sure that all the requirements are fulfilled in the design. This has been done by adding an extra section to the Design Brief. Validation is making sure that the design fulfils all the needs of the stakeholders. This was quite a hard step in this project because the stakeholders are (imaginary) and cannot actually check the design themselves. Therefore, some assumptions have been made about the views of these stakeholders.

Systems Engineering makes use of loops. Each loop will use the process shown in *Figure 2.* The first iteration loops are shortly described below and the final loop is shown throughout the report.

2.1 First iteration loop

In the first loop the first pieces of information were written about the scope of the system, the environment and the connection between the two. Also, the most important stakeholders have been discussed and the most important requirements have been put in the design brief. A first version of the FAST diagram with an object tree was created, but was minimalistic and very basic Most information was written into keywords and small sentences. Furthermore, two concepts for the underground parking garage. The best concept was chosen by using a multi criteria analysis. The concepts and the multi criteria analysis are shown in chapter 6. For the sustainability part two pieces of the underground parking garage were chosen on which circularity was going to be applied to in further loops. For the structural part the forces of the buildings on top has been calculated.

2.2 Second iteration loop

In the second loop the stakeholder analysis has been expanded and new requirements have been found. Also, the regulations for a parking garage were investigated and have been put in the design brief. All these new regulations were used to make the design more detailed and make it conform the regulations. The keywords and small sentences made in the first loop were transformed into full text. The FAST diagram was also significantly expanded. The other things that have been done is translating the design from paper into a digital design in Microsoft Visio, making big steps calculating the forces of the groundwater on the parking garage in the structural part and find and write about circularity. For the financial part big steps have been made in making a table with the cashflow of the future parking garage.

3. Input

3.1 Analysing the project environment

The first step in the project preparation is analysing the project environment. The reason for doing so is that the environment imposes limiting conditions, regulations and frameworks that a system has to comply with. Besides, the developments take place in the environment could affect the system.

The municipality of Enschede together with the organisation LIFE have created a new project located in the city centre, this project will be called the Kop van Boulevard. The ambition of the project is to renew the city, enhance the attractiveness of the city and improve housing. Therefore, the area will get a radical transformation to facilitate a variety of new functions, such as business, housing, recreations, shopping and so on. One of the main priorities of the project is that sustainability will be pursued, this will be done by focussing on energy usage, the circular economy, biodiversity, climate adaptation, mobility and social sustainability. Also, an expressive architecture style will be achieved (Gemeente Enschede). *Figure 3* shows an impression of the new project with a comparison with the current situation.

Figure 3: Comparison Kop van Boulevard Project (left - Gemeente Enschede) and current situation (right - Google Earth)

The complete Kop van Boulevard project will provide around 545 new apartments, 1050 m^2 of commercial area, 1100 m^2 for offices, 650 m^2 for the catering industry and an underground parking area. The infrastructure around the system will also be modified (Municipality of Enschede, 2018). *Figure 4* shows the infrastructure in the current situation and the planned situation. What can be concluded from this figure is that the main change regarding the infrastructure is that the roundabout between the streets Boulevard 1945, The Haaksbergerstraat, Ripperdasstraat and Nijverheidsstraat will be transformed into a cross section with traffic lights. Also, the entrance of the underground parking garage the Van Heekgarage will be shifted more towards the cross-section.

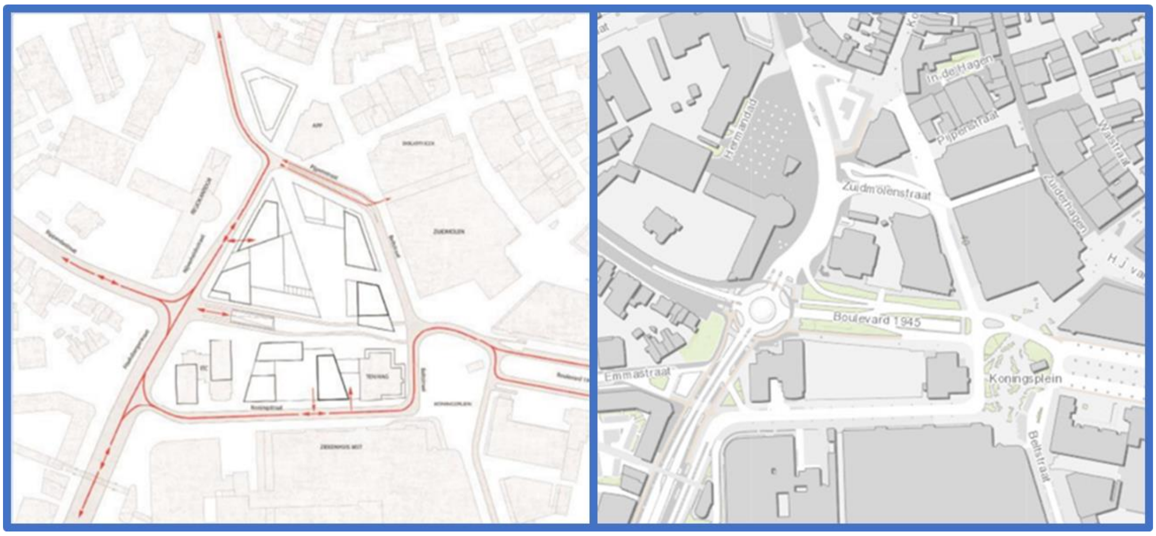

Figure 4: Comparison between the intended situation (left - (Gemeente Enschede, sd)) and the current situation (right - (Kavelaanbod Enschede, 2019))

As already stated, one of the new developments of the project is the construction of a brand-new underground parking garage, which is the system of this project. It is known that the system must have parking spaces for apartment owners and shop owners. Next to the system itself, the project focusses on the connection to the Van Heekgarage and current access roads of the city of Enschede. The system has also to be future proof, so that it can be used for other functions in the future. Not part of the project is the design and construction of the upper ground architectural plans of the Kop van Boulevard project as a whole.

Between the system and the outside world there are a lot of interactions. To start with the people that park their car or bicycle in the parking garage. At some time, they will also take the vehicle and leave the parking garage so there is a bi-directional interaction. Besides, the municipality wants to attract people that want to recreate or shop and therefore there will be more space for pedestrians and cyclists. However, it is given that shop visitors should park there car elsewhere. It is likely that there will be a new interaction to the redesigned area and for example the Van Heekgarage. Besides, the area is connected to the current city centre of Enschede and it is likely that more people from the city centre will visit the Kop van Boulevard area.

3.2 Stakeholder analysis

In this part the involved stakeholders are going to be discussed. A stakeholder is an organization of person that influences or will be influenced by the project. The stakeholders will have different views and demands for the project. It is therefore important that these demands are taken into account to satisfy the stakeholders and create support for the project.

Firstly, all the different stakeholders will be discussed and shown what their view is on the project. Then these stakeholders are going to be examined on their power and interest. This information is going to be used in the next chapter, the requirements analysis, to formulate requirements with all the stakeholders involved in the project.

Involved stakeholders

Users of the parking garage

The first group of stakeholders that are going to be discussed are the users of the underground parking garage. The inhabitants of the new apartments will be using the parking garage on a daily basis. The main concern for these inhabitants is that they are able to park their car in the parking garage. Also, storage units should be available to fulfil their needs. These storage units should be spatially and easily accessible. Another group that will use the parking garage on a daily basis are the workers of the above located shops. The workers of the new shops demand that they are able to park close to their job. The users of the underground parking area have a large interest in the project because they are ultimately, as their name insinuates, the people that actually will use the garage on a daily basis. Their power on the other hand is not that big because they do not have the resources available to try influence decisions made.

Clients

The municipality of Enschede is one of the most important stakeholders involved in the project. This is because they are one of the two clients involved in the project. For the municipality the parking garage is a part of the city's ambition to renew the city, enhance the attractiveness of the city and improve housing. It is necessary that the parking garage fulfils all the demands of the municipality to be able to call the project a success. The other client is the investor of the whole Kop van Boulevard project called 'LIFE'. This investor who pays for the project is looking for selling it at the end of the construction to another party. Without both clients the project is not possible, that is why they have both much power, also their interest in the project are high. This is because the organisation LIFE will try to make money from the project by selling it and the municipality's target is to improve the city, as already stated above and in the analysation of the project environment.

After the construction is done another important stakeholder will get involved. This stakeholder will be the company that will buy the garage from the organisation LIFE. The main important goal for this organisation is that they will earn back the money spent buying the underground parking garage in the shortest time possible in order to make as much profit as possible after that, this makes them have a big interest in the project. Their power however, is moderate because they will buy the project when finished, so they cannot influence decisions made during the design and construction phase. Also, there could be the situation that more buyers are interested in the project and thus reduce the power of one buyer.

Emergency services: Fire department

Another group of stakeholders involved in the project are the emergency services, in particular, the fire department. It is important is that they are able to react to potential events in the underground parking area to the best of their ability. If this is not the case the fire department will not be able to react to possible situations in the underground parking area as intended. This will cause that the building will not be safe and therefore cannot be put into use. This ensures that they will have a high amount of power. Their amount of interest in the project will be lower than their power, this is because when the regulations have been met, they will not care what happens after that with the construction and the design.

Land owners

The parking garage and other aspects of the new realisation of “Kop van Boulevard’ will be realised at the location where currently the buildings ING bank and ‘Hub Twente’ are located. These buildings have to be demolished in order to carry out the project. This will cause that these buildings have to be purchased from the owners. This results in that these companies have a big interest in the project. which can cause heavy resistance from these owners. However, it is not the case that the land owners can ask a high value for the building to get as much money as possible or to scare of the clients. This is because an independent appraiser will value their buildings. This amount has to be paid by the municipality in order to buy them, resulting in that their power is not that big.

Neighbouring residents

The destruction of the existing buildings and the construction of the new buildings will cause a substantially amount of disturbance for neighbouring residents. This results in that these residents will have a negative view on the project. Also, the roads have to be transformed which will cause that the traffic needs to take a detour when the destruction and construction take place. Nevertheless, the project could also benefit the neighbouring residents when constructed. This is because the new area will give new opportunities for shopping. It will maybe cause that the land value of the neighbouring residents will rise, which is obviously a benefit for them. Above mentioned reasons will cause that the neighbouring residents will have a relatively high interest in what happens when the construction phase will commence. Their power however, for the same reasons as for the residents, is little.

Salespeople

The salespeople are going to rent or sell the above located apartments. In order to do so they demand that the assets corresponding to the apartments will be as attractive as possible in order to attract as much future residents as possible and to increase the prices of the apartments as high as possible. Two of these assets included into the project are the underground parking area itself and the storage units. The salespeople have quite some interest in the parking garage, because it influences the money they are going to make on the apartments. They however do not have the power to have a big impact on the project.

Demolition companies

At the end of the lifecycle of buildings, demolition companies are uncharged to demolish or dismantle the structures. Due to the imminent scarcity of raw materials these companies present information about materials which can be reused or the possibility to recycle the parts of the system. The mentioned companies should be able to disassemble easily the parts of the parking garage at the end of its lifecycle. They want to spend less time in deconstructing the structure and to reuse the materials of the construction.

Environmental companies

The last stakeholder that is going to be discussed are the environmental companies. What is meant with the environmental companies is the impact of the construction and demolition of the underground parking garage on the environment. The demolition is already further explained in the previous stakeholder. Humanity currently does not live in a sustainable way. An important indicator for this is earth overshoot day, as the organisation itself explains:

“Earth Overshoot Day marks the date when humanity’s demand for ecological resources and services in a given year exceeds what Earth can regenerate in that year” - Earth overshoot day 2019

Therefore, circular principles will be integrated in the parking garage to help improve this situation to help the environment. The power is quite high because it is also an important priority of the municipality in the whole ‘Kop van Boulevard’ project to implement sustainability as explained in the project exploration. The interest is quite average, this is because a circular parking garage would be a small part of the solution for a global problem.

Power-interest grid

Next, the position of the stakeholders will be identified. This will show how important all the involved stakeholders are in the project. The stakeholders will be ranked on power and interest in a power interest grid which were described in the previous part. The power interest grit is shown in *Figure 5.*

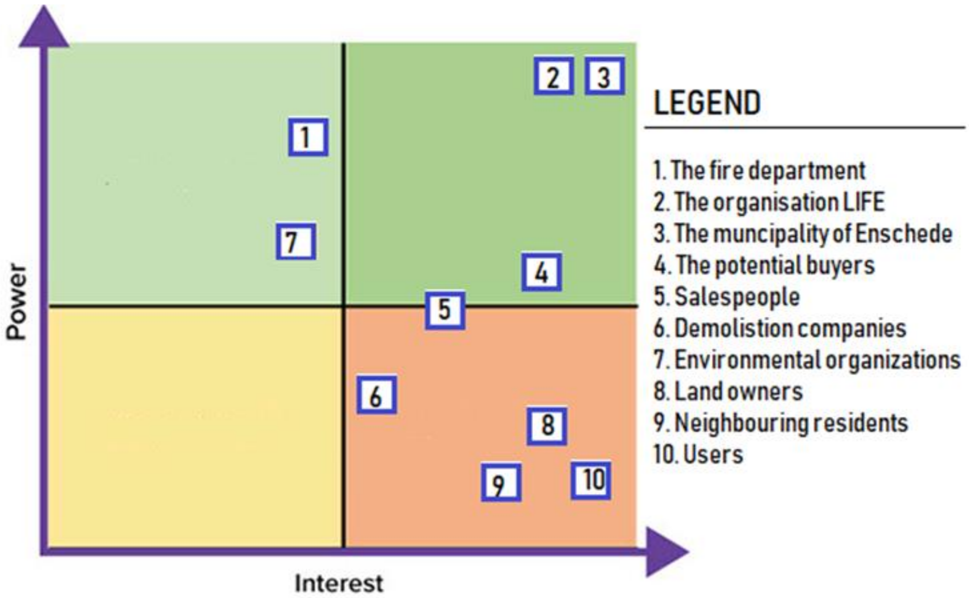

Figure 5: Power-interest grid

4. Requirements Analysis

The next step in the System Engineering process is to find out what the demands, needs and wishes are of the stakeholders and how these can be satisfied. Also, other requirements that are not discussed by the stakeholders have to be determined. This will be done in chapter 4.2. Firstly, the requirements will be discussed based on the demands, wishes, expectations and needs of the different stakeholders involved in the project.

4.1 Stakeholder requirements

Users of the parking garage

Inhabitants of the new apartments

One of the main changes in the area of the Kop van Boulevard is the construction of new apartments. The inhabitants of the new apartments are therefore an important stakeholder, which are taken into account. The main requirement from these inhabitants will be that there is a possibility to park their car close to their apartment. With the realisation of the underground parking garage, the system, this is possible. Besides, every apartment owner wants a store room close to the parking garage. Both these things should be able to do in a save manner. The storage room should provide enough room to provide capacity for two bikes and some shelves for storing goods. The last important requirement is that the complex must be easily accessible, from both the apartments and the road system.

Shop owners and workers

Next to the apartments there will be space for shops. Given is that shop owners are able to park their car in the new underground parking garage and this is therefore also a requirement of them. Shops are depended on the amount of people that come and spend their money. Therefore, when the decision is made to make the parking garage openly available, they want the shop to be easily accessible with every kind of vehicle. Also, it must be stimulated for people to come from the city centre to the Kop van Boulevard.

Clients

Municipality of Enschede

The municipality of Enschede is the problem owner of the project. However, a problem owner is also a stakeholder and has therefore requirements. With the building of the parking garage the municipality wants to fulfil several requirements. First the parking garage should contribute to urban quality, improve the accessibility in the area and incorporate a variety of functions. Another requirement is that the garage needs to be future proof, which means that the garage can be used for other functions in the future.

The organisation ‘LIFE’

As already stated in the stakeholder analysis is that the organisation ‘LIFE’ will build the project in order to become the owner of the complex. They are looking for a party after the construction to sell the project too. It is therefore important that this investor will not lose money on the project risking they quit the project, and thus stopping the project in its entirety. After this the municipality will have to look for a new organisation, which will take some time.

Both clients have stated the technical requirements that they parking garage should have in order to make the parking garage function properly. These requirements are called limiting conditions, because if these conditions are not met, the project will fail. The limiting conditions for the project important for the clients are that there should be enough parking spaces for 331 apartments and 2540 m^2 of commercial area, that there should be storage rooms for 331 apartments and that the parking garage will be connected to a new built underground roundabout.

Potential buyer of the parking garage

The potential buyer of the parking garage main focus is to maintain the parking garage to generate revenue. For exploiting the parking garage some requirements are needed. The first one is that there should be a control room inside the building where security cameras can be checked and users can be helped. This control room should be big enough for the equipment necessary to do those things and there should also be facilities available for the people working in the control room. Also important for the maintenance is that the parking garage is connected to all the utilities like water and electricity. There should also be a solution for keeping the parking garage clean.

Emergency services: Fire department

The main requirement from the fire department is that the system satisfies the safety regulations that are stated in national policy for an underground parking garage in order to react to potential events in the underground parking area to the best of their ability. The first thing regarding to this is that the systems located in the parking garage are capable in locating potential events, these systems are cameras, heat and smoke detectors. Secondly, is that the equipment is available on site to react to events, like connection points for fire hoses, enough entrance points to get to the situation as fast as possible and ventilation to suck up smoke.

Land owners

The current land owners, ING and Hub Twente, will have to move to another place. This is because their land is going to be used for the project. Therefore, their requirement is that the municipality will provide a sum to purchase their buildings in order to demolish them. It is not the case that the land owners can ask a very high value for the building to get as much money possible or to scare of the clients. This is because an independent appraiser will value their buildings. This amount has to be paid by the municipality in order to buy them.

Neighbouring residents

The neighbouring residents do have requirements, the most important requirement is that the nuisance is kept limited. This requirement however is mainly focussed on the construction phase, which will not be included in this project.

Salespeople

As already stated in the stakeholder analysis is that the salespeople are mainly focussed on selling the apartments for as much as possible. The requirements resulting this is that the parking garage and storage unit must look as attractive as possible to ensure that the design should appeal to possible buyers. This can be done by making a spacious storage unit and simply by making the parking garage look nice.

Environment

The requirements resulting from the environment is that two circular principles should be integrated into the parking garage to support sustainability.

Demolition companies

The main requirement for the Demolition companies is that they can remove and recycle the parts easily, without spending too much time. They also require that the waste caused by the dismantling of the parking garage should be reduced. It is also important that the different removed parts can be re-used for other purposes in the future. For instance, the implementation of precast concrete in the construction of the parking garage, makes the demolition companies to spend less time in dismantling the structure. Also, precast concrete elements like slabs can be reused as fences.

4.2 Other requirements

In this part requirements will be discussed by covering the system from different angles to find requirements that where overlooked by the stakeholders.

Requirements regarding structural design

No stakeholder has mentioned something about the structural design, but it is an important part of the design. Therefore, some requirements are necessary in order to make a functional parking garage. The first requirement is that the parking garage should be able to cope with all the forces from the on top located buildings and the forces from the parking garage itself. There are also forces working on the walls caused by the water level and soil. Finally, it is important that the parking garage will not prolapse, to prevents this the design of a sufficient foundation is needed to cope with this problem.

Requirements from national policy

There are a lot of requirements stated in national policy about many different topics, for example requirements regarding the dimensions of the entrances, parking spaces and safety regulations. It is important that the parking garage will meet all these requirements. Because otherwise the parking garage will be rejected and things have to be improved, which will cost time and money.

Requirements regarding the interaction between the systems environment

The requirements included in this part are the requirements that result from the connection between the system, the underground parking garage, and the environment, the situation around the parking garage. The first requirement is that the dimensions of the parking garage should not be bigger than the maximum dedicated area, it is however possible to differ the dimensions somewhat within this area. The depth of the parking garage is not included in this area. So, the number of floors the parking garage will have is not bounded, it is however recommended to not exceed 2 floors because of financial and constructional reasons.

4.3 Design brief

In this part the requirements found in the previous two parts are going to be converted into a design brief. A design brief is a structured representation of all the requirements, sorted on their function. All the requirements will be made Specific, Measurable, Acceptable, Realistic, and Time-bound (SMART). Each requirement in the design brief will firstly be briefly described, then the criterion shows in which units the requirement will be shown, the performance shows the quantitative value for the units described on which the requirements should meet and the bandwidth shows how much this value can deviate. After this it is shown what the source is of the requirement. The last column shows if it is a requirement, limiting condition or a wish. Requirements can be negotiated. Wishes are also negotiable but less important than requirements. Limiting conditions cannot be negotiated. All the requirements stated in policy are considered as limiting conditions, this is because these requirements are not negotiable. The design brief is shown in Appendix A.

5. Functional Analysis & Allocation

5.1 FAST Diagram & Object Tree

In this chapter the functionality of the system will be determined. The functionality of a system is a description of what must be able to do. The functional analysis leads to a description of the system in functional terms. The core concept of the functional analysis is the meaning of “function”. A function is a description of an action or process needed to achieve a certain goal. It is a combination of a verb and a noun. The begin of the function tree is the task. The task is a description of the client’s need and the reason for the system’s existence, will be determined. The functions will be sorted into basic and supporting functions. A basic function is essential for the execution of the task. If a task has no basic function, the system will not work properly. Supporting functions are exceptionally important for the client’s degree of acceptance. In contrast to the basic functions, they are not essential for the execution of the system’s task. The functions are placed in a Functional Analysis System Technique (FAST) diagram is based on asking two important questions that reveal valuable information. These are the “How?” and “Why?” questions:

- From general to specific (from left to right): ask the “How” question;
- From specific to general (from right to left): ask the “Why” question.

After these objects can be found for a particular function. All the objects together form the object tree. The FAST diagram combined with the object tree is shown in Appendix B.

5.2 Requirements Allocation Sheet (RAS)

Important is that all the requirements shown in the design brief have a corresponding function in the function tree which is connected to an object in the object tree. This also important the other way around, that all the functions and objects in the FAST diagram have a corresponding requirement. This has been assisted by a Requirements Allocation Sheet (RAS) diagram, which will help to find if there is a corresponding function and object for each requirement. A requirement without function or object is useless, and the other way around. The RAS diagram is shown in Appendix C.

6. Design Synthesis

Now the functions and objects for the parking garage are determined, the designing of the parking garage can start. Important for the design is that all the objects from the object tree are included in the design. The design synthesis start with showing the two concepts that are made and after that a multi-criteria analysis is conducted. One concept is worked out to a preliminary design and this one will be discussed extensive.

6.1 Conceptual designs

In this part the two concepts will be evaluated which were drawn in the first loop of the Systems Engineering process.. This will be done by using a multi-criteria analysis.

Concept 1

The main idea in concept 1 is that the area of the available space is divided into two parts. The first part for storage units and the second part for parking area. The right part will be used for the parking area, this is done because the entrance of the parking garage will be located here. This makes automatically the left part available for the storage units. The concept is the same on both levels and uses a system with one-way traffic. A drawing of the concept is shown in *Figure 6*. The benefits of this concept are that firstly, the parking places are easily accessible because the users do not have to drive all across the structure to find parking spaces. The second benefit is that the separation between the storage units and parking spaces makes it easy for users to know what area is where. There is a better organization between the people that go to the parking spots and the people that go to the storage rooms, because they are separated from each other. On the other hand, it will be less accessible for the people that lives in other buildings which are not above the storage units to reach them.

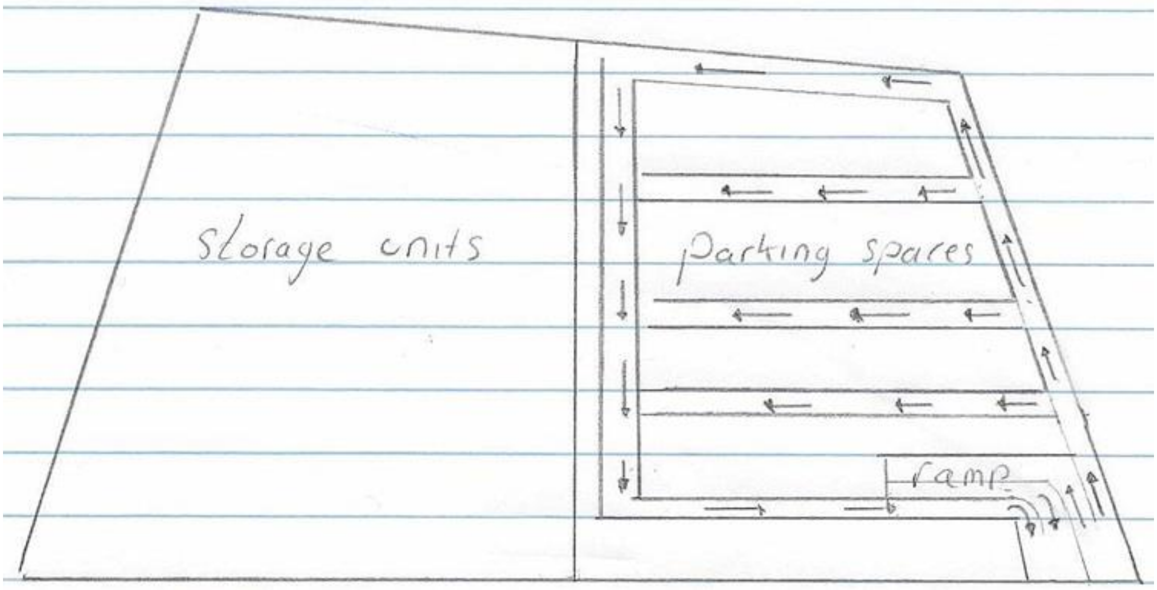

Figure 6: Conceptual design 1

Concept 2

The second concept will implement the parking spots in the middle of the roads as it is shown in *Figure 7*. This will take place in the first and second floor in which there will be a one-way road system. The storage units are distributed over the area on the borders of the parking garage. Meaning that the residents of the apartments above the parking garage can easily reach them. Furthermore, it will be safer for the people that want to go to the storage rooms. Because, they do not have to cross the entire parking garage due to the fact that each section in which the storage rooms are placed is going to have stairs and elevators. This concept makes the parking garage very accessible for pedestrians because they can easily reach their cars along the garage. On the other hand, the accessibility for the cars will be a little bit complicated because there is only one entrance and the parking spots at the top will be far away from it. Finally, the space in which the parking spots are located can be used for other purposes at the end of the lifecycle of the parking garage.

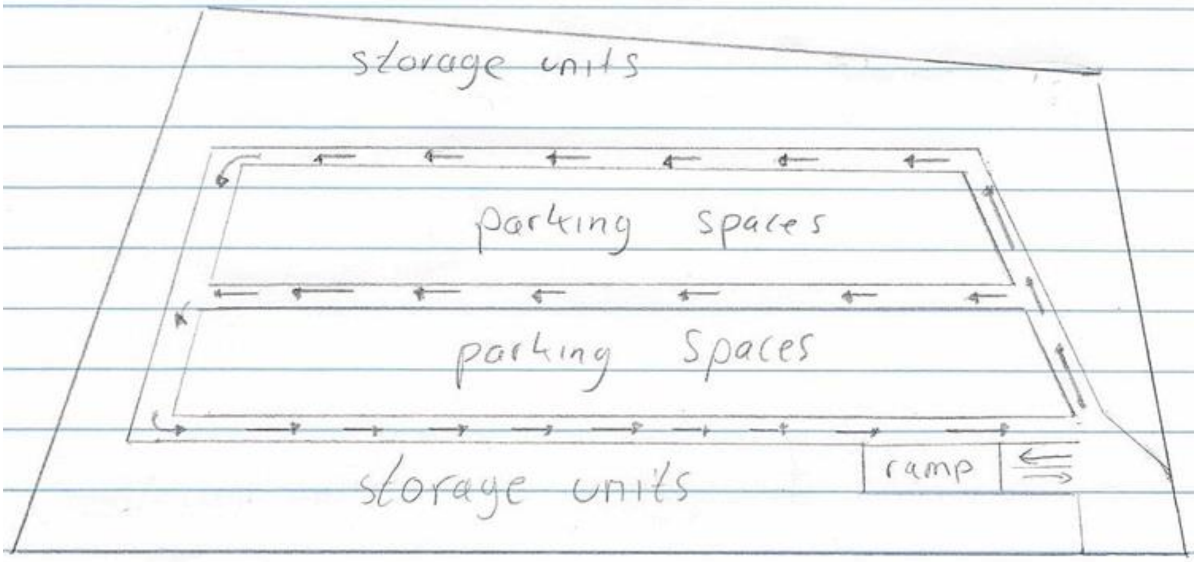

Figure 7: Conceptual design 2

6.2 Multi-criteria analysis

The best concept will be chosen by using a multi-criteria analysis. The evaluation criteria with the corresponding results are shown below.

Evaluation criteria

Accessibility

Discussed with the accessibility of the parking garage is how easily the users can enter and leave the parking garage. So, how easily the cars can access the parking area, how easily the storage units can be reached with vehicles from the public road system and finally, how the storage units and parking area can be reached from the buildings on top. The easier the different parts can be reached, the higher the score. The accessibility is going to be evaluated in two parts: for pedestrians and for cars.

Accessibility for pedestrians

When the storage units are distributed over the parking garage like it is the case in concept 2 means that these units can easily be accessed from the different building on top from all sides, which are located on the border of the parking garage. If the storage units are placed on one side in the parking garage, like it has been done in concept 1, this will cause that the people who live on the other side of the parking garage have to walk across the whole parking garage to access their storage unit. This also the case the other way around, that people have to walk to the other side when walking from their parked car to the buildings on top. What can be concluded from this, is that the accessibility for the pedestrians in concept 2 is higher.

Accessibility for cars

The accessibility for cars is in both concepts seems quite the same, this is because the entrances in both concepts are both located at the same place, as is the ramp to go to the other floor. The difference occurs when it is examined how long it takes to reach some parking spots. This difference is that in concept 2 the distance between the parking spots the furthest away from the entrance is bigger than this distance in concept 1. This results in that concept 1 scores better than concept 2.

Safety

Discussed with the safety requirement is how safe people are in the parking garage. As already stated in the accessibility requirement is that in concept one people have to move across the parking garage to access their storage units. This will cause that these people have to move over the parking area, which is not as safe as the situation in concept 2. Because in this concept people can almost directly access their storage unit without having to cross a road. The same goes for the people who are going to park their car and walk towards the shops or apartments.

Spatial distribution

The spatial distribution of the different objects implemented in the parking garage should be practical, which means that all the room available is used in the best way possible. This will be analysed by considering which of the two concepts have some remaining space which is not a used. The concept that has more remaining space will receive less points in the multi-criteria analysis. Due to the fact that the parking spots will be separated from the store rooms in the two floors. The roads for the parking spots should be placed just for a few parking spots in each row, which leads to lose space. In the second concept the store rooms will be placed at the borders of the parking garage. Therefore, the roads will be made for a considerable number of cars in each row which is more feasible. Therefore, concept 2 scores more points.

Flexibility

An important requirement from the Municipality of Enschede is that the parking garage should be flexible. What is meant with this requirement is that the structure of the underground parking area can be used for different purposes when the parking garage is not needed anymore. The more flexible the design, the higher the score. Concept 2 has a more open region in the parking area in comparison with the first concept because of the parking area in the middle. This causes that the structure in the second concept can more easily by transformed for another purpose.

Multi-criteria analysis: Table

The points awarded for the different evaluation criteria is shown in *Table 1.*

Table 1: Multi-criteria analysis

	Accessibility for pedestrians (x 2)	Accessibility for cars (x 2)	Safety (x 3)	Spatial distribution (x 2)	Flexibility (x 1)	Total
Concept 1	2	4	2	3	2	20
Concept 2	4	3	3	4	3	31

What can be concluded from this multi criteria analysis is that concept 2 would be the best option. That is why this concept is going to be elaborated further for the final design in the following loops.

6.2 Preliminary design

A preliminary design can be described as the development of a general overview of a building object, so that it offers a good impression of for example functional and spatial design, general dimensioning and incorporating of guidelines and regulations. The preliminary design is divided into different parts with corresponding drawings. First the general floor plan of the parking garage will be introduced and some parts of the parking garage will be shown in detail. Besides, the lighting plan, ventilation plan and safety plan of the parking garage are discussed.

Floor plan

As it was mentioned before three loops have taken place. In the first loop the concept was selected. The design started being developed in the second loop. Finally, for the third loop the design was made in more detail. The floor plans of the first and second floor are shown in *Figure 8 & 9.* The project developed floor plans for the first and second floor of the parking garage in which it is shown where are going to be located the different elements and facilities for the users. The parking garage has the same shape as the space occupied by the residences above.

For the first floor there is going to be an entrance in which there is a ticket machine. Next to the entrance there is also the control room (green space in drawing). The drivers can place their cars in the different parking spots, they have to follow the one-way road system. The different storage rooms are located in the borders of the parking garage. Therefore, stairs and elevators where placed in order to facilitate the accessibility for the residents of the apartments to the different storage rooms. The parking spots for the disabled are located on this floor close to the elevator. In order to access the second floor a ramp is included.

For the second floor plan the ramp is also included. As it was stated in the first floor plan the storage rooms are going to be located at some borders of the parking garage. In order to get to the different parking spots the drivers will also use the one-way road system. As it can be noticed there are more store rooms and less parking spots in this floor than in the first floor.

The area around the storage units is made yellow in the drawings to make clear that it is a pedestrian zone only.

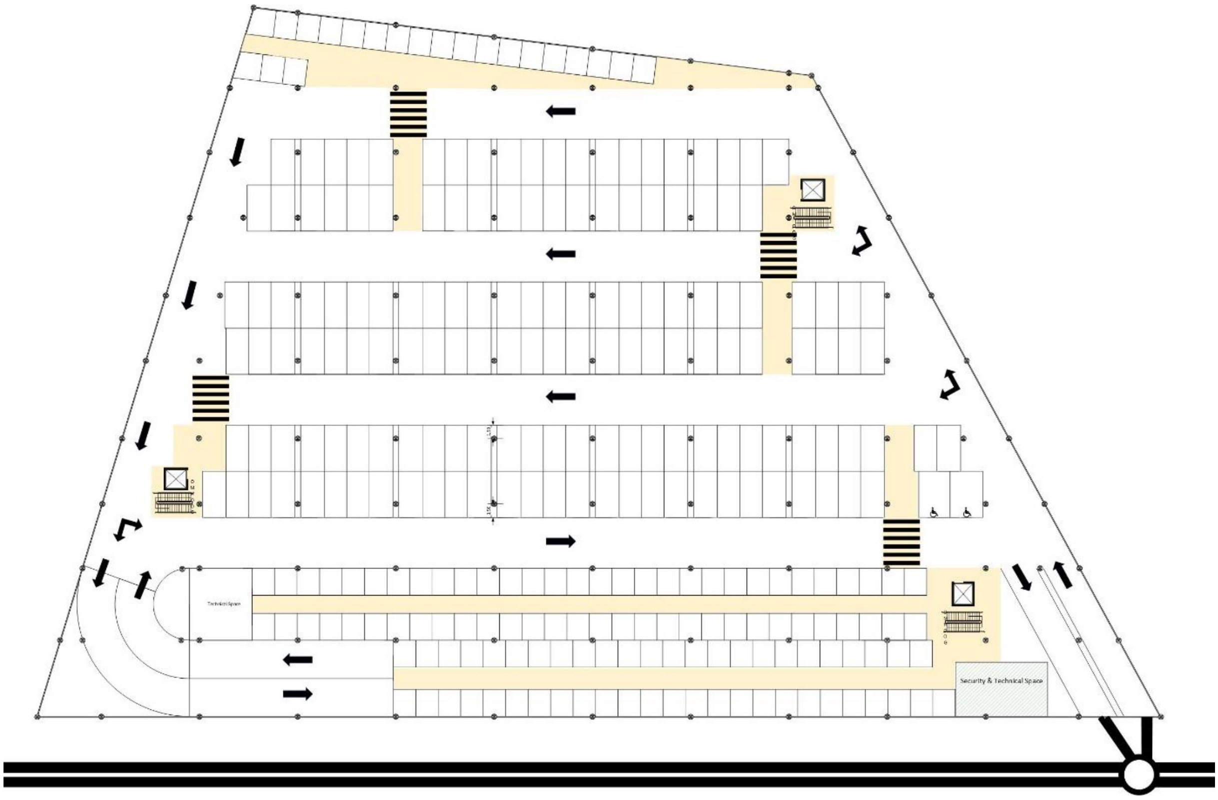

Figure 8: Preliminary design - Floor plan -1

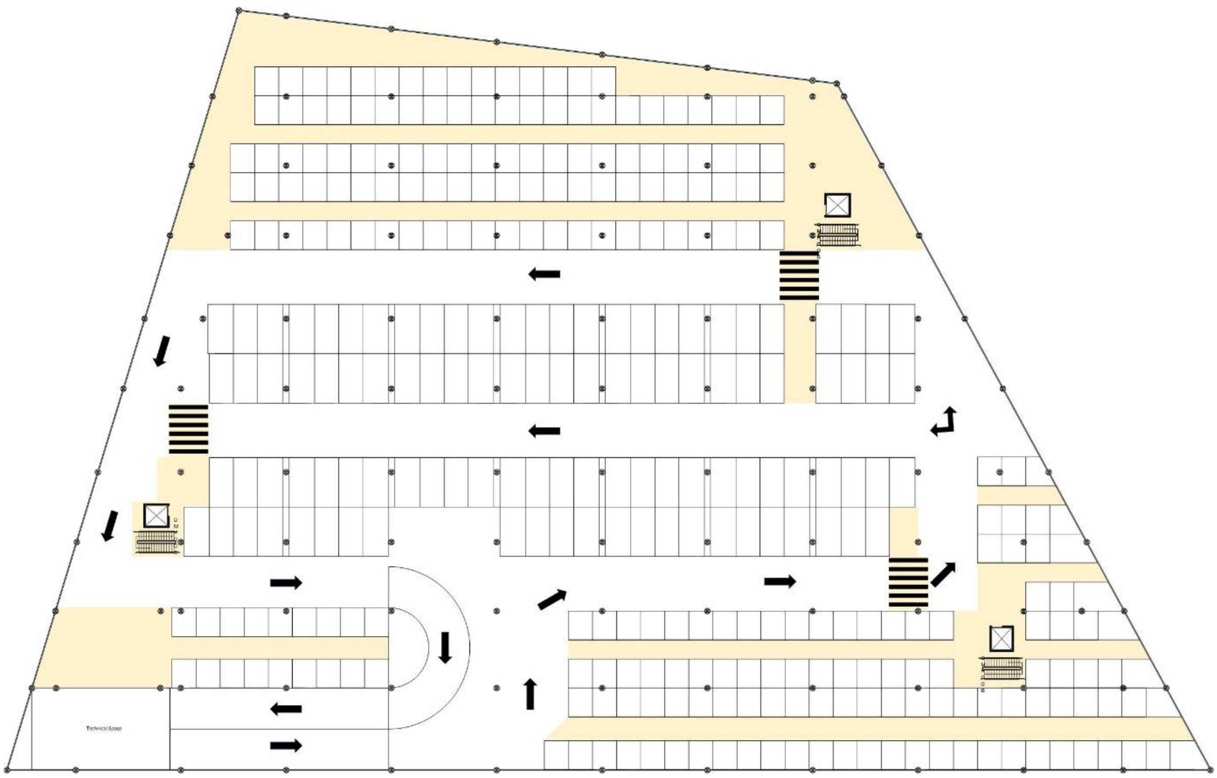

Figure 9: Preliminary Design - Floor plan -2

Entrance

There is one entrance for the whole parking garage in which two barriers are implemented in order to control the entrance and exit of vehicles. It is going to be connected to an underground roundabout which also accesses the Van Heekgarage. As *Figure 10* shows, the width of the cross section is 5,8 m. At the gate drivers get a ticket and which they use afterwards to pay at the ticket machine. The ticket machine is located next to the entrance. The machine will put a stamp in the ticket which will allows the drivers to leave the parking garage. The mentioned ticket will have to be inserted in the ticket machine at the gate in order to be able to leave the parking garage.

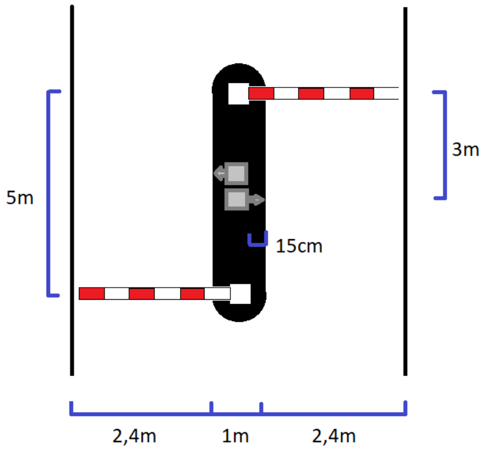

Figure 10: Preliminary Design - Entrance Parking Garage

Control room

The control room is located next to the entrance. It is equipped with a toilet for the employees and a relaxing area. This place will function as a place to provide information/help to the users of the parking garage. Furthermore, it is possible to know the activity in the parking garage captured by the cameras. In *Figure 11 and 12* 2D and 3D drawings are shown to give an impression of the control room.

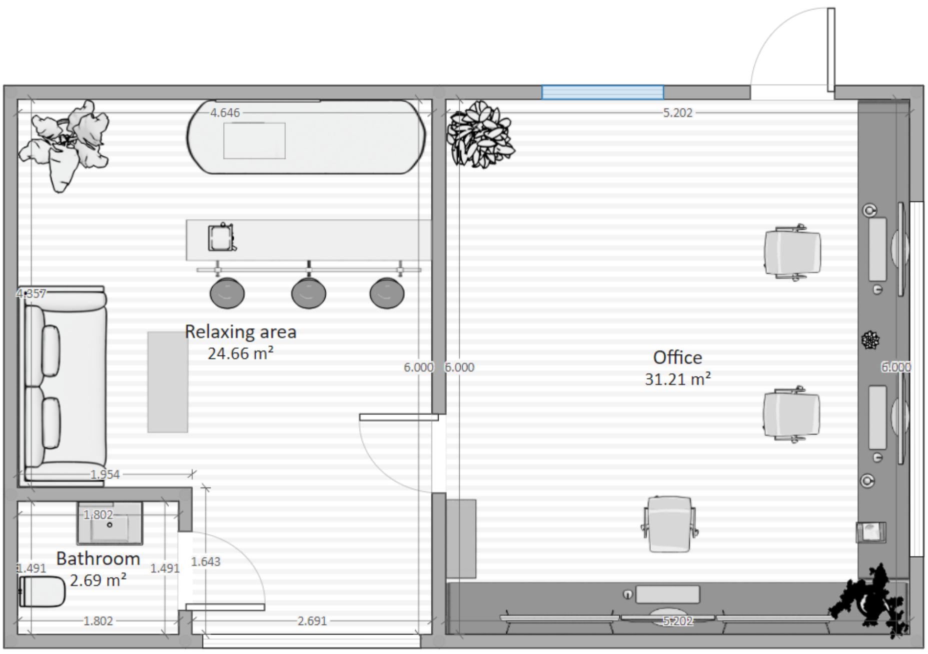

Figure 11: Preliminary Design - 2D Design Control Room

Figure 12: Preliminary Design - 3D Design Control Room

Lighting plan

In the parking garage Light as a Service (LaaS) provided by Philips will be used, this principle will later further be explained in Appendix G. Philips made a plan how the lighting should be placed in a parking garage when LaaS has been used (Philips Lighting, 2019). This plan dictates that 1 LED fixture (WT460C LED35S / 840 VWB) should be placed per 2 parking spots. They should be located parallel to the roadway and in the middle of the parking garage. For the roadway, it is dictated that also 1 LED fixture (WT460C LED35S / 840 VWB) should be placed in the middle and above the road. This is feasible for roadways of a width up to 6 meters. For the hallways between the storage units the same fittings will be used as in the drive ways. In the storage units itself other fittings have been used, these are Philips Led ceiling lamps (Moire 6W=40W 2700k). How all the different luminaires have been positioned is shown in the lighting plan. The complete lighting plan is shown in Appendix D.1

As it was mentioned before the lighting plan was planned with the implementation LED fixtures. The selected type was WT460C LED35S / 840 VWB, which is shown left in *Figure 13* The light in the storage units is shown on the right side in *Figure 13.*

Figure 13: Lights used in the parking garage (Philips Lighting, 2019)

Ventilation plan

The ventilation was calculated with the help of a car park simulation (Thunder Headeng, 2019). This source served as a base to calculate how many ventilation systems have to be implemented in the parking garage. In order to implement the fans some values were taken as a base for the first floor we made an estimation which result in 12 ventilators for the first floor. The calculation of exhaust openings resulted in a value of 4. In the second floor 9 ventilators were calculated and 1 big exhaust opening is going to be implemented with a length of 14 m. The ventilators that are going to be used are illustrated in *Figure 14*. It is important that the different ventilation systems should be able to handle a certain amount of L/s. Therefore, this calculated for the first and second floor. The area where the storage units are located was taken into account. For the first floor the area was 4272 m^2 and should be able to handle 3 L/s (NEN 2443-2013). Which leads to the value of 12816 L/s. For the second floor the calculated area was 3120 m^2. The same calculation steps are applied given a value of 9360 L/s. A drawing of the ventilation plan can be found in Appendix D.2

Figure 14: Ventilator used in the parking garage (Thunder Headeng, 2019)

Security plan

In the security plan the cameras were implemented at the corners of the parking garage. The cameras have a view range of 90 degrees therefore, it is feasible to implement 15 cameras. The cameras where placed strategically one at the entrance, another was placed near the ramp. And the rest will be placed along the parking spots. Finally, the cameras will be placed in the storage rooms in order to have an overview of the whole parking garage and to provide safety to the stuff of the residents. The cameras will also be useful, because there are only employees from Monday till Saturday (8 hours a day). The whole security plan is shown in Appendix D.3.

Safety plan

In order to ensure the safety for the people in case of possible emergencies different elements will be placed. The mentioned elements are heat detectors, smoke detectors, LPG detectors, carbon monoxide detectors and sprinklers. The heat detectors range is 25 m^2 (IFSEC Global, sd), as it can be appreciated in Appendix D.4 is they are located per two parking places, because the service area of two parking places is 25.7 m^2 even though, it was stated that they should 104 m^2 (IFSEC Global, sd) this is done because the surface area of 8 parking places is 104 m^2. LPG detectors and carbon monoxide detectors are situated every 200 m^2. It is stated that they should be located every 400 m^2 at a height of 1.5 m (NEN 2443:2013). The group decided to place them on the columns which leads to that the range is halved, this is because the columns are not in the middle of the parking spots. Finally, the sprinkles should be located beside the heat detectors which means that they are going to be placed every 25 m^2 and for the storage units the sprinklers are going to be located above the hallway per 2 storage rooms. Information about the regulations regarding the connection for the fire department are stated in NEN1594. However, this document was not accessible, so an assumption has been made. The total area of one floor is 4830 m^2 and the assumption is that there should be at least one connection point inside an area of 1700 m^2. Then, the safety plan shows 3 connections near to the staircases and elevators, which will facilitate that firefighters can extinguish the fire faster. This is shown in Appendix D.4

7. Verification and Validation

In this chapter the verification and validation of the previous evaluated design will be described. Verification is used to evaluate the requirements shown in the Design Brief with the actual design. The verification takes place during two phases. The first one takes place in the design phase to check if the design made meets all the requirements. The second verification takes place when the design has been constructed. But since this project has not been constructed yet, a forecast has been made on how this should be done when the project is constructed. The verification of both steps will be made visible in a matrix. Described in this matrix are:

- When the design is going to be verified?
- Who has the responsibility to verify the design? This will during the design mostly be done by us, the design group. After construction this will mostly be done by a potential builder.
- Furthermore is shown how the design will be verified, this can be done by doing an analysis, simulation, using a benchmark, product information and finally which an inspection done by an expert.
- Finally shown in the matrix, is the result of the verification. The matrix is shown in Appendix E.

Validation is done to check if the stakeholders agree with the design. The most important validation moment is after the construction of the project. Therefore, validation will determine whether the project meets their expectations. They will give feedback in order to take corrections and appropriate measures to satisfy their concerns. This should assure that all the systems work as they should.

8. Structural Design

In the System Engineering process all the design aspects of the new parking garage are determined. This chapter is an introduction on the Structural Design. In the Structural Design the structure of the parking garage is described and calculations for the construction are made. The Structural Design will be further explained in Appendix F.

When beginning with the calculations of the parking garage, it is necessary to know the dimensions of the structure. The top view of the garage is shown in *Figure 15.* In this figure the placing of the columns can also be seen. The maximum span between the columns is 10,95 meters. This has to do with the amount of parking spots between the columns. There can also be seen that not all columns are on the same vertical line. This is for example because of the turn left below which will lead to the ramp to go downwards.

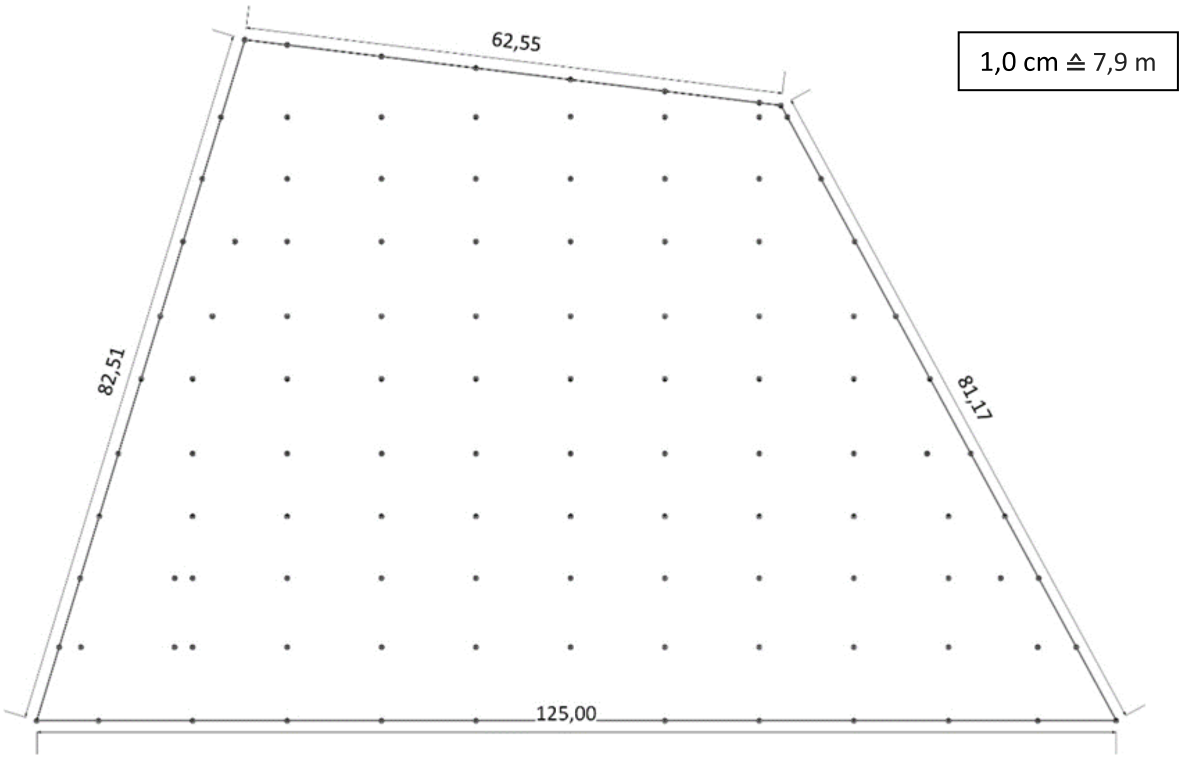

Figure 15: Dimensions of the parking garage (all dimensions in meters)

As there can be seen in *Figure 16,* which is in top view, the distance between the columns on the horizontal line differ sometime. This is done because of the length of the road and the length of the parking spots. One parking spot must be 5,13 meters long and 2,5 meters wide. But because there is a column between some parking spots, the parking spots that are right next to the column must be increased by 0,15 meter. This will make those parking spots 2,65 meters wide.

Furthermore, the road must be 5,66 meters wide because of the 90 degrees parking spots.

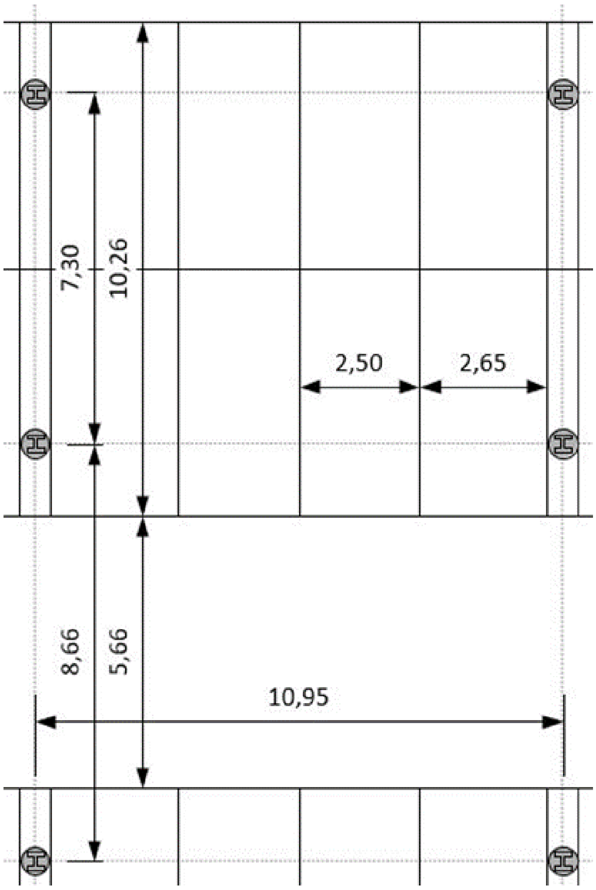

Figure 16: Dimensions of the parking spots and distance between columns (all dimensions in meters)

Furthermore, the parking garage will consist out of two floors. The height of each floor, from topside floor to topside floor, is 4 meters. The side view of the structure can be seen in *Figure 17.*

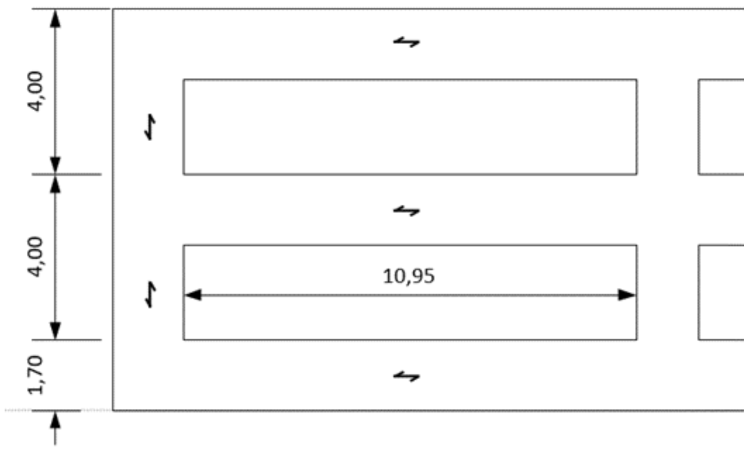

Figure 17: Height of parking garage (all dimensions in meters)

In the top view of the foundation design, *Figure 18.*, there will be placed beams on top of the columns. The ground and water around the garage will give pressure to the walls. Because of the beams, the structure will not collapse because it will provide pressure to the other side of the walls.

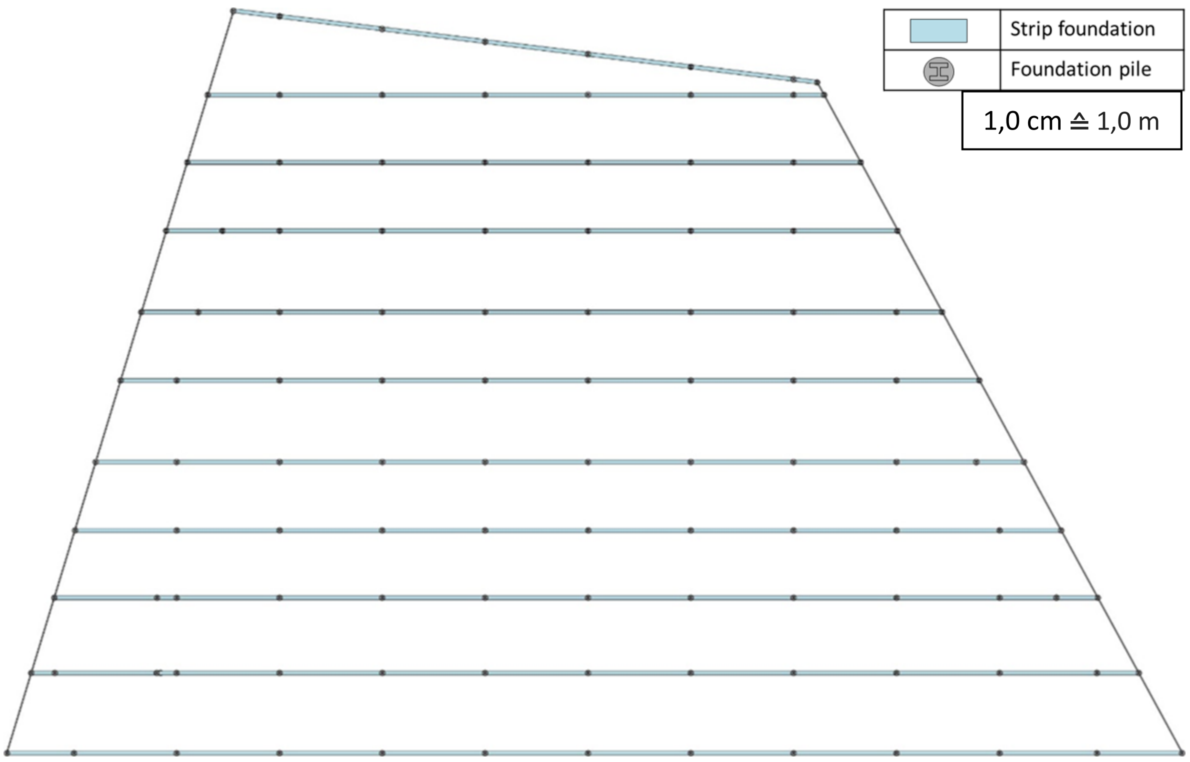

Figure 18: Foundation design

8.1 How to withstand water

During the constructing of the parking garage the (ground)water is a big problem. This is because the ground water level in Enschede is really high. The water can cause a delay in the schedule of the construction and is also a threat to the safety of the workplace. To handle the water from an open construction there are a few solutions.

Firstly, the most simple one is to use gravity drain. This solution will be making use of drainage channels that will carry away the water from the working area.

Secondly, water pumping will also carry away the water from the working area.

At last, the use of sheet piles may be necessary. This can be used when a low permeability soil is found. This will not fully prevent the water problem, but it is a good start. When the ground water level is really high, the use of a pump may still be necessary.

In the construction of the parking garage there will be made used of sheet piles and pumps. This is because the sheet piles secure safety so the structure will not collapse and the pumps will make sure that the rain and ground water will not cause any problems. The water that will be pumped away will go to a wooded buffer or channel. The water can only go to the channel when the water level of the channel is not too high, otherwise it will cause nuisance.

9. Circular Economy & Sustainability

Circular Economy is an economic system in which the minimization of the consumption of raw materials is aimed. Large volumes of material are used in the construction sector, which at the end of the lifecycle of the constructions generate waste flows. Therefore, the concept of Circular Economy has gained acceptance. The Netherlands has been recycling the demolition waste which usually serves as foundations for different infrastructures. Even though, scarcity of natural sources is a problem for the construction of buildings. The environmental impacts caused by the construction materials are the main concern. For that reason, the concept of Circular Economy has been boosted.

The first step to apply circular construction will be taken in the design phase. This will be done by considering how demolition companies work and the technical requirements of the new building in order to recycle the different elements at the end of their lifecycle. Circular constructions changes to cooperation, knowledge sharing and transparency between the different architects and contractors involved in the construction of the different infrastructures (Rijkswaterstaat, 2015).

For the construction of the parking garage it was decided to implement Circular and Sustainable principles. The current linear models adopted by the construction companies starts with the production and ends in the demolition which eventually generates waste. The current way in which constructions are designed have many drawbacks. One of the main drawbacks is the lack of raw materials due to de continue demand which is not sustainable for the future. Raw materials are also expensive because some of them are available to a limited extend (Het Groene Brein, 2019). Another disadvantage of the current linear model are the environmental impacts which are caused by the demolition waste and consumption energy in the production processes.

On the other hand, the application of Circular Economy has significant benefits. This application resulted in a significant reduction of greenhouse emissions. Because, it is possible to use renewable energy instead of the conventional fossil fuels. There is a reduction in cost of raw materials. Furthermore, the products do not lose too much of their value despite being used. These products are manufactured in order to last longer and to recover the different components easily and given them a new purpose (Het Groene Brein, 2019). These benefits are essential for the construction of the parking garage, because the different stakeholders want to spend less money and the demolition companies wants to be able to dismantle the different parts easily at the end of the lifecycle of the parking garage. These will also comply with the requirement which states that it causes less environmental damage in order to support the sustainability for the future.

Specifically, two objects will be implemented with Circular and Sustainable principles. The mentioned elements are: concrete and the lighting system. The implementation of these two objects will bring some important benefits for the different stakeholders. Concrete elements are feasible to be used in other constructions at the end of their lifecycle and when it is referred to the lighting system its different parts can be recover easily and be reused or recycle. Benefits of the elements are discussed in detail in Appendix G.

10. Finance

In this part of the report a financial analysis of the parking garage is conducted. For this analysis, it is assumed that the parking garage is commercially exploited instead of making it only private parking. The first part of the financial analysis is a forecast of relevant project cash flows. A cash flow overview is made in Excel for a period of 15 years. After 15 years, a terminal value is determined. Next, the cash flows are assessed in terms of the net present value (NPV), internal rate of return (IRR) and payback period to check whether the project is feasible for an investor. Finally, a sensitivity analysis is done to see what the effects of the discount rate are on the NPV.

10.1 Project cash flows

The first step in the financial analysis is to make clear the cash inflows and outflows of a parking garage. This is done by determining the different cash flow items and put them in an Excel overview, which can be found in Appendix H. The cash flow overview is made for a period of 15 years. This period is chosen to see the development of some cash flow items over time. For example, according to maintenance cash flow. Once in ten years there is big maintenance and that will lead to extra an extra cash flow. With a period of 15 years, the effects of big maintenance on the total cash flow of that year and coming years can be studied. Both cash inflow and outflow will now be discussed.

Cash inflow

Parking fee

For the parking fee three different rates are used, namely a hour rate for general public, a subscription for residents and a subscription for workers. The rates are based on current rates from parking garages in the neighbouring area: Q-Park Centrum, H.J. van Heekgarage and Stationsplein. An overview of those parking fees is shown in *Table 2*. (Gemeente Enschede, 2019) (Q-Park, 2019)

Table 2: Parking fees current parking garages Enschede

Parking Garage	Average rate per hour	Rate parking subscription residents per year	Rate parking subscription workers per year
Q-Park Centrum	€ 2.20 (€ 0.55 per 15 min)	€ 1128.84 (€ 94.07 per month)	€ 1162.60 (€ 138.55 per month)
H.J. van Heekgarage	€ 2.90	€ 1684.00	*Not possible*
Stationsplein	€ 2.90	€ 565.00	€656.00

In Praktijkboek Parkeergarages is stated that the operator of a parking garage wants a parking rate that cover the minimal cost. Besides, it should be attractive for people to park their car in the garage compared to other parking garages or street parking. The rates that are used in the cash flow overview for the new parking garage are shown in *Table 3*.

Table 3: Parking fees new parking garage

Rate per hour	Subscription residents per year	Subscription workers per year
€ 2.20	€ 565.00	€ 656.00

Occupancy rate

The occupancy rate of parking garages in the Netherlands lies on average between 30% and 40%. In 2016 the municipality of Enschede conducted a parking study and the conclusion was that there are enough parking spaces available. The occupancy rate of parking garages in Enschede varies for general parking between 15% and 61% and for private parking between 13% and 61%. (Gemeente Enschede, 2016)

For the new parking garage at the Kop van Boulevard both general and private parking are included. According to the study, the average parking occupancy in Enschede is 38%. It is assumed that the total occupancy rate at the start 34% is and over time by brand awareness the rate will increase to 42%. The variation that is assumed is 4 percentage point.

The total occupancy rate will be subdivided over the different parking rates. Therefore, a parking survey in the city of Delft is used, where the parking rate for a same size garage is 45%. 41% of that is short parking and 4% is parking by drivers with a subscription. Because it is assumed that residents of the new apartment complex with a car will park their car in the garage, the occupancy rate for subscription will be higher. (Parkeren Delft B.V., 2017) The following occupancy rates are used in the cash flow model:

Table 4: Occupancy rates

General public	45% of the total parking occupancy
Subscription: Residents	50% of the total parking occupancy
Subscription: Workers	5% of the total parking occupancy

Advertising

As an extra source of income for the parking garage, advertising will be implemented. This means that advertisers can promote in the parking garage via the so called Abri's and Mupi's. These are advertising mediums of about 2 m^2 big. It is also for the municipality an opportunity to highlight sights to the visitors of the city. To determine the revenue of advertising, information of the municipality of Breda and Deventer is used. (JCDecaux, 2018)

The revenues of advertising in Breda are on average € 316,000 per year for 369 advertising mediums. In Deventer three parking garages together generate € 6,000 per year. Based on these values a constant advertising value is assumed. For the complete parking garage we assume that there are 10 advertising mediums available and on average they will generate € 8,000 per year. (Gemeente Deventer, 2007) (Gemeente Breda, 2013)

Total cash inflow

As mentioned in the part about the occupancy rates, the cash inflow by parking fees will increase over the years. In *Table 5* are the cash inflows of year 1 and year 15 shown.

Table 5: Cash inflow year 1 and year 15

Cash inflow: Year 1		**Cash inflow: Year 15**	
Parking fees	€ 748,675.41	Parking fees	€ 924,834.33
Advertising	€ 8,000.00	Advertising	€ 8,000.00
Total cash inflow	€ 756,675.41	**Total cash inflow**	€ 932,834.33

Cash outflow

Building cash flow

The first cash flow item that has to be determined for the cash outflow is the building cash flow, basically the investment for the project. For the cash flow overview, the building cash flow is split into cash flow for building works, installations and some remaining cash flow. Values of Bouwkostenkompas for a completely deepened parking garage ≥ 2500 m^2 are used to calculate the cash flows. In the overview the abbreviations BVO, TBB and BGT are used. BVO is the gross floor area *(= bruto vloeroppervlakte)*, TBB is the gross total built-up area *(= totaal bruto bebouwd)* and BGT is the gross total facade *(= bruto gevel totaal)*. At the installations part cash flows for the Lightning as a Service (LaaS) system by Philips and the water pump are added. An overview of the building cash flows is shown in *Table 6*. (Bouwkostenkompas, 2019) (Philips Lighting, sd)

Table 6: Building cash flow

Building works	**Unit**	**Cost/unit**	**BVO/TBB/BGT**	**Costs**
Constructional substructure	m^2 TBB	€ 460.32	9200 m^2	€ 4,234,944.00
Constructional superstructure	m^2 BVO	€ 4.45	9660 m^2	€ 42,987.00
Construction facade	m^2 BGT	€ 0.07	25 m^2	€ 214.13
Installation excl. user	m^2 BVO	€ 5.79	9660 m^2	€ 55,931.40
Finishes	m^2 BVO	€ 77.77	9660 m^2	€ 751,258.20
Remaining building costs facilities	m^2 BVO	€ 3.27	9660 m^2	€ 31,588.20
Total building works				€ 5,116,710.55
Installations	**Unit**	**Cost/unit**	**BVO**	**Costs**
Water installations	m^2 BVO	€ 38.03	9660 m^2	€ 367,369.80
Climate-control installations	m^2 BVO	€ 23.70	9660 m^2	€ 228,942.00
Lighting system (LaaS)				€ 34,610.00
Electricity installations	m^2 BVO	€ 29.70	9660 m^2	€ 286,902.00
Transport installations	m^2 BVO	€ 2.88	9660 m^2	€ 27,820.80
Pump installation				€ 1,000.00
Total installations				€ 1,053,457.00
Remaining	**Unit**	**Cost/unit**	**BVO**	**Costs**
Permanent establishment	m^2 BVO	€ 2.91	9660	€ 28,110.60
Indirect building costs	m^2 BVO	€ 123.42	9660	€ 1,192,237.20
Total remaining				€ 1,220,347.80
Total building cash flow				**€ 7,283,702.95**

Maintenance cash flow

Maintenance includes the organizational and technical activities that have as goal to keep the parking garage in a good condition so that it can fulfil its main function. For the cash flow overview a distinction between preventive, daily, small maintenance, and multiannual, big maintenance is made. An example of preventive maintenance is the reparation of a lamp and renewing of the climate control system can be seen as multiannual maintenance. In *Table 7* the maintenance cash flow is shown. It is assumed that big maintenance will take place once in 10 years. (Rinsma & Koens, 2007)

Table 7: Maintenance cash flow

Maintenance	**Cash flow per parking place**	**Total cash flow**
Preventive, small maintenance	€230.00	€56,350.00 per year
Multiannual, big maintenance	€300.00	€73,500.00 per 10 years

Employee cash flow

Another cash flow item is the employee cash flow for the management of the parking garage. For this item the minimum wage stated by the government is used, namely €23,552.88 per year. It is assumed that there are employees available in the parking garages from Monday till Saturday (8 hours per day) and the parking garage is open 24/7. (Rijksoverheid, 2019)

Lighting cash flow

For the new parking garage a Lighting as a Surface (LaaS) system of Philips will be implemented. Therefore, values of Philips are used to determine the value of cash flow by lighting. The assumptions made for the calculation are stated in the table below. (Philips Lighting, 2019)

Current consumption	€ 141,422.00
Lamp replacement	€ 1.50 per m^2 per year
Potential saving	45%

With these assumptions the following calculation (*Table 8*) is made with the calculation tool of Philips. (Philips Lighting, sd)

Table 8: Cash flow lighting system

Current operational costs	€ 141,422.00
Saving	- € 63,640.00
Philips LaaS-rate	+ € 34,610.00
Benefit	€ 29,030.00
Lighting cash flow	**€ 112,392.00**

Water cash flow

The water cash flow is determined with the current water price, which is on average € 0.63/m^3. The water that is used by the parking garage will mainly be for the employees and for the fire protection system. However, water for the fire protection system will of course only be used if there is a fire. Therefore it will be neglected for the cash flow overview. The amount of water used by an employee is on average 7.1 m^3/fte, so that means that in a year 52 * 7.1 = 369.2 m^3 water will be used by the employees of the parking garage. The cash flow per year for the water use is then: 369.2 * 0.63 = € 232.60. (Milieubarometer, 2019) (Vitens, 2019)

Energy cash flow

The energy cash flow is calculated with the current energy price of € 0.23/kWh. The average energy use per parking space lies between 50 and 800 kWh/parking space per year. For the cash flow overview, the average value will be used, namely 425 kWh/parking space per year. The parking garage consists of 245 parking spaces so the total energy in a year is 245 * 425 = 104,125 kWh. This results in a cash flow per year of 104,125 * 0,23 = € 26,031.25. (Milieubarometer, 2019) (Milieucentraal, 2019)

Total cash outflow

All the cash outflow items can be summed up. Because the maintenance cash flow differ once in 10 years, the cash outflow will also differ once in 10 years. In *Table 9* all the cash flow items for cash outflow are summed up.

Table 9: Total cash outflow

Cash outflow: Small maintenance		**Cash outflow: Big maintenance**	
Maintenance cash flow	€ 56,350.00	Maintenance cash flow	€ 129,850.00
Employee cash flow	€ 23,552.88	Employee cash flow	€ 23,552.88
Lighting cash flow	€ 112,392.00	Lighting cash flow	€ 112,392.00
Water cash flow	€ 232.60	Water cash flow	€ 232.60
Energy cash flow	€ 26,031.25	Energy cash flow	€ 26,031.25
Total cash outflow	€ 218,558.73	**Total cash outflow**	€ 292,058.73

Terminal value

A terminal value, or residual value, determines the value of a business or project beyond the forecast period of 15 years, when future cash flows can be estimated. For the cash flow overview the "perpetual growth" model will be used. This model assumes that a business will continue to generate cash flows at a constant rate forever, in our case that is a discount rate of 4.5%. The terminal value can be calculated with the following formula: (Investopedia, 2019) (Brealey, Myers, & Allen, 2011)

$$Terminal\ value = \frac{Annual\ netto\ cash\ flow}{Discount\ rate} \qquad \text{Eq. 1}$$

The annual net cash flow depends on the values for the cash inflow and outflow.

- For the cash inflow it is assumed that the car occupancy rate remains 42% and the prices for the parking garage remain also the same. This results in a constant cash inflow of € 932,814.47 per year.
- The cash outflow is also assumed to be constant over time. The only cash flow that differs once in 10 years is the maintenance cash flow. However, for this calculation we assume that the extra cash flow for big maintenance is spread out over a period of 10 years. This results in a constant cash outflow of:

$$Cash\ outflow = €\ 218{,}558.73 + \frac{€\ 73{,}500.00}{10} = €\ 225{,}908.73$$

This gives a net cashflow of: $Netto\ cashflow = €\ 932{,}814.47 - €\ 225{,}908.73 = €\ 706{,}905.74$

$$Terminal\ value = \frac{€\ 706{,}905.74}{1.045} = €\ 676{,}464.82$$

10.2 Financial assessment

The second part of the financial analysis of the parking garage is the financial assessment. Three methods will be used to assess the parking garage in a financial way, namely the net present value (NPV), internal rate of return (IRR) and the payback period.

Net present value (NPV)

The present value (PV) is the actual value of a future sum of money or stream of cash flows. The net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. The net present value can be calculated with the following formula: (Investopedia, 2019) (Brealey, Myers, & Allen, 2011)

$$NPV = C_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} \qquad \text{Eq. 2}$$

Where:

- C_0 = the investment at time 0 of the project;
- C_t = cash flow at time t, so the future cash flow;
- t = year of cash flow;
- r = discount rate.

The investment at time 0 is in this case the building cash flow of the project: €7,283,702.95. The discount rate for this cash flow is 4.5%. The workgroup Discontovoet has set this discount rate for public physical investments and infrastructure. (Werkgroep Discontovoet, 2015) With these values and the net cash flows of each year the NPV can be calculated. To draw up correct conclusions, the NPV is calculated after 5 different years. The NPV after 5, 10, 15 and 20 years are chosen to see the change of the NPV after short periods and NPV after 50 years is chosen, because that is on average the maximum life span of a parking garage. The values are shown in the table below.

NPV after 5 years	€ -4,736,552.65
NPV after 10 years	€ -2,366,245.65
NPV after 15 years	€ -347,111.71
NPV after 20 years	€ 1,242,668.19
NPV after 50 years	€ 6,034,675.28

These values can be analysed with the NPV-rule. This rule states that investors should only invest in projects that have a positive net present value. This follows from the theory that a positive net present value indicates that the projected earnings generated by a project exceeds the anticipated costs.

It can be concluded that if the use of the parking garage is only 15 years as used in the cash flow overview, that the project is expected to result in a net loss for the investor. To create profit with the parking garage, it should function longer than 15 years. After 20 years the NPV is positive and if the parking garage will operate during its complete life span the NPV will be more than 6 million euros.

Internal rate of return (IRR)

The IRR is a discount rate that makes the net present value (NPV) of all cash flows from the project equal to zero. The difference between the opportunity cost of capital and the IRR is that the IRR is a profitability measure, that depends solely on the amount and timing of the project cash flows, and the opportunity cost of capital is a standard of profitability, that is used to calculate how much the project is worth. (Investopedia, 2019) (Brealey, Myers, & Allen, 2011)

To access the project the IRR-rule will be used: the investment project will be accepted if the opportunity cost of capital is less than the internal rate of return ($r < IRR$). It can be concluded that a project with an IRR greater than its cost of capital is a profitable one, and therefore it is interesting for a company to undertake such projects. IRR in practise is calculated by trial and error, because there is no analytical way to compute when NPV will equal zero. For our project cash flow the IRR after 15 years is calculated with an formula in Excel.

The IRR after 15 years = 3.8%. This value is lower than the discount rate of 4.5% and therefore according to the IRR-rule it is better to not invest in this project. A possibility is to increase the time that the parking garage will be used. For example, the IRR after 20 years is 6.3% which means that the project will be profitable.

Payback period

The last method to assess the cash flows of the project is to look at the payback period. This can be found by counting the number of years it takes before the cumulative cash flow equals the initial investment. The payback rule states that a project should be accepted if its payback period is less than some specified cut-off period. For the new parking garage the cut-off period in the cash flow overview is 15 years. The payback period can be calculated with the following formula:

$$Payback\ period = \frac{Investment}{Annual\ netto\ cash\ flow} = \frac{€7{,}283{,}702.95}{€714{,}275.60} \approx 10\ years \qquad \text{Eq. 3}$$

The investment in this formula is the building costs of the parking garage and the annual net cash flow is the value that is used in years without big maintenance. According to the payback rule, the project should be accepted because the payback period of 10 years is less than the cut-off date of 15 years. (Brealey, Myers, & Allen, 2011)

10.3 Sensitivity analysis

A sensitivity analysis determines how different values of an independent variable affect a particular dependent variable under a given set of assumptions. For the sensitivity analysis of the cash flows from the parking garage, the effect that changes in discount rates has on the net present value (NPV) will be examined. First a good scenario with a discount rate of 3.5% will be examined and after that a bad scenario with a discount rate of 5.5%. In *Table 10* the results of the sensitivity analysis are shown. (Investopedia, 2019)

Table 10: Sensitivity analysis

	Good scenario: r = 3.5%	**Normal scenario: r = 4.5%**	**Bad scenario: r = 5.5%**
NPV after 5 years	€ -4,662,073.20	€ -4,736,552.65	€ -4,807,785.98
NPV after 10 years	€ -2,103,898.71	€ -2,366,245.65	€ -2,609,565.02
NPV after 15 years	€ 182,358.61	€ -347,111.71	€ -823,908.08
NPV after 20 years	€ 2,070,387.33	€ 1,242,668.19	€ 517,168.81
NPV after 50 years	€ 8,627,839.43	€ 6,034,675.28	€ 4,051,691.43

Good scenario

For the sensitivity analysis of the good scenario, a discount rate of 3.5% is used to look at the effects on the NPV. A lower discount rate results in more certainty and that will give a higher present value of the future cash flow. To make a good comparison with the normal scenario, the same NPV's will be calculated namely after 5, 10, 15, 20 and 50 years. What directly can be derived from the table is that the NPV after 15 years is in the good scenario positive, where it was in the normal scenario negative. In the cash flow overview it is assumed that the parking garage will be used for only 15 years. As mentioned earlier, with a discount rate of 4.5% this project is not feasible for the investor. With a lower discount rate, it is feasible because the NPV after 15 years is now € 182,358.61. Looking at the NPV after 50 years, the average lifespan of an underground parking garage, the difference is more than 2 million euros between the good and normal scenario. A lower discount rate would be a good option to make the project more profitable. (Fool, 2019)

Bad scenario

In the bad scenario the discount rate is 5.5%. The higher discount rate results in less certainty and that will give a lower present value of the future cash flow. In table 13 the comparison of NPV’s between the bad scenario and normal scenario is made. When using the NPV rule for the bad scenario after 15 years, the outcome of it will be the same as for the normal scenario: both NPV’s are negative. This means that the parking garage with a use of 15 years is not feasible for an investor. However, when the discount rate is 5.5% the values of the NPV after 20 years and 50 years are much lower. A higher discount rate will make the project less feasible compared to the normal scenario.

Comparison

In *Figure 19* the different scenario’s are visualised with the NPV’s plotted over time. What is clearly visible in this figure is that the discount rate has much influence on the NPV and indirectly also on the choice of the investor to invest in a project or not.

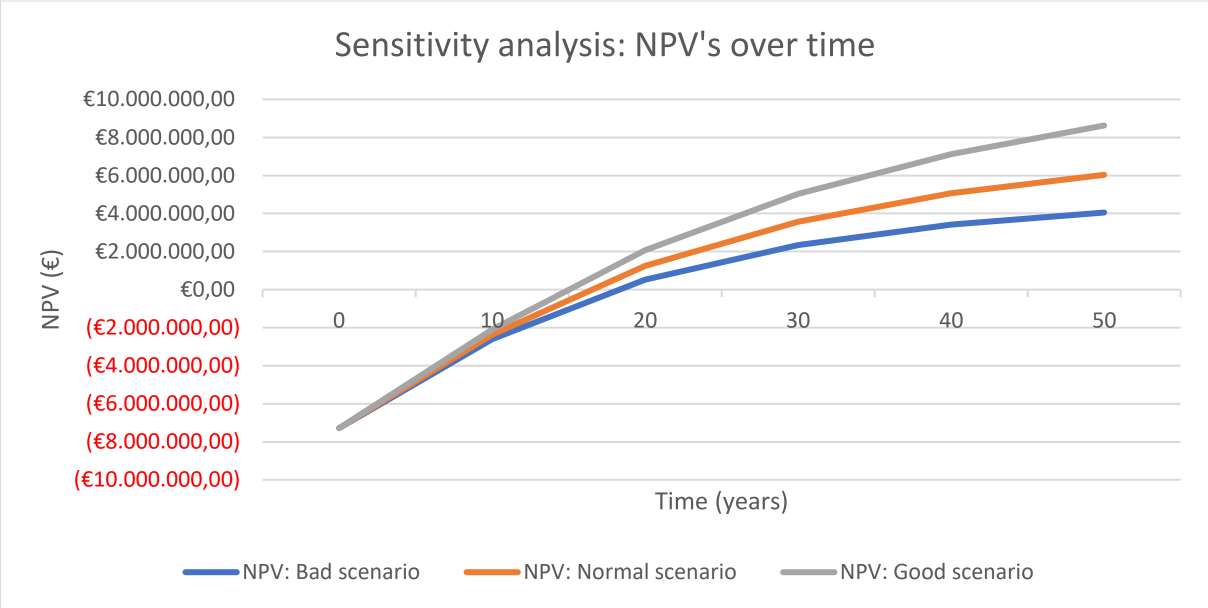

Figure 19: NPV's over time

11. Discussion

In every project there are some thing that can be improved. This is because there are always thinks that are left out or changed during (end of) the project.

It will be feasible to analyse more in deep how the supply chain is going to be organized. This will help to know other options in terms of transportation of materials. For the concrete it will be better to investigate other options after at the end of its lifetime in the parking garage. Maybe, it is possible to find a more worthy purpose for them. It is important to mention that for the LED lighting, Philips is going to take care of the different parts of the lighting fixtures. Meaning that as a group is not our worry to find a purpose for the different parts as in the case of the pre-cast concrete.

As already has been mention in the chapter of mechanics, the values of the forces of the beams are not correct. This probably has to do with the fact that there has been something that could be left out. But due to time pressure there was not a change to check the calculation again and come up with a solution.

Furthermore, the calculation of the sheet pile is not really correct either. This comes to the fact that in reality there is no hinge on the sheet pile but there is a point which will serve as an hinge. This point can be calculated by making use of Q-, V-, M-diagrams.

At last, for finance the assumption is made that the exact amount of parking spots has been met. But in the floor plan it became clear that the exact amount of parking spots are a bit more, to be exact 256 parking spots.

12. Conclusion

The new parking garage at the Kop van Boulevard is an important part to realise the ambition of the municipality. The municipality wants to renew the city, enhance the attractiveness of the city and improve housing. A radical transformation in the area is needed to realise the ambition. Next to the parking garage, apartments for about 500 residents will be realised and there will be space for shops. This will also attract visitors of the city to come to the renewed area. With the new parking garage, there is space created for residents to park their car.

As a design firm, the design is conducted with the Systems Engineering process. In three loops a preliminary design is established. Within these loops the main steps are conducted: Requirements Analysis, Functional Analysis & Allocation and Design Synthesis. The verification and validation step at the end makes it clear if the parking garage satisfies the requirements and functions that are drawn up.

Within the design process, circular principles are applied. With the theory of Circular Economy & Sustainability the idea of it is explained and two objects in the parking garage are implemented with the C&S principles, namely concrete and circular lighting system. Besides, construction calculations are made for the Structural Design of the parking garage.

To check whether the parking garage is financially feasible, a financial analysis is conducted. In this analysis it was assumed that the parking garage will be commercially exploited. Cash inflows and outflows are determined and with that financial assessments were conducted in terms of NPV, IRR and payback period. What was clear is that with a discount rate of 4.5% it is not feasible to build and use a parking garage for only 15 years. However, the average lifespan of a parking garage with good maintenance is approximately 50 years and therefore it is also possible to exploit the parking garage longer than 15 years.

Putting all these parts together, it makes it possible for the municipality to realise the ambition. Taking into account a structured design process, circular principles, a structural design and a financial analysis makes this report a complete overview of all the important components of building a parking garage.

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Appendix

A: The Design Brief

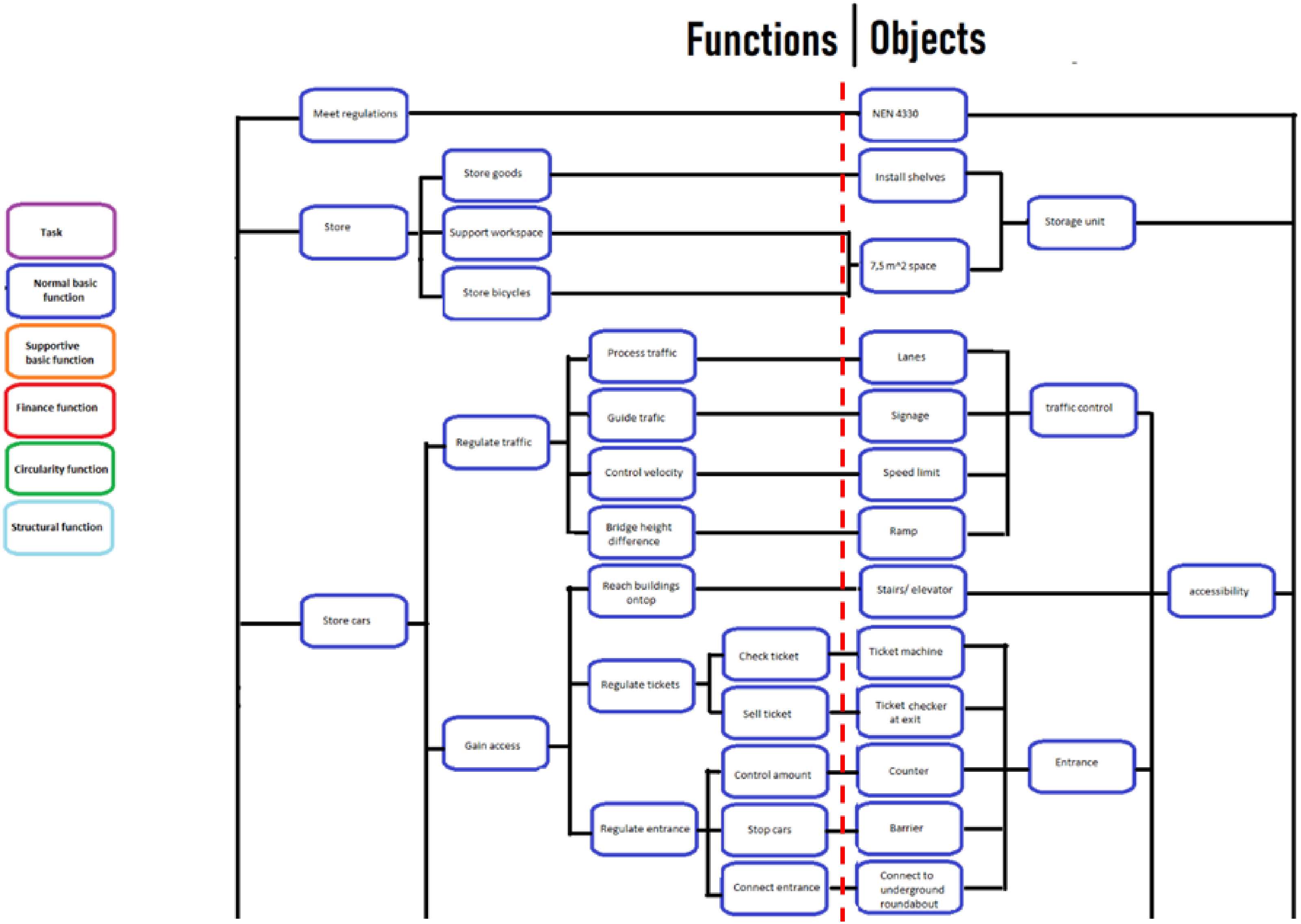
ID	Description	Criterion	Performance	Bandwidth	Priority	Source
1.	**Storage unit**					
1.1	The storage unit should be spacious	Area in m^2	9	min 6	reqmt	client
1.2	There should be space for bikes	Number	2	min 1	reqmt	client
1.3	There should be space for storage	Number of shelves	2	min 2	reqmt	client
2.	**Entrance**					
2.1	The number of entrances into the parking garage for vehicles	Number	1	min	cond	policy
2.2	Number of lanes into parking garage	Number	1	1 is enough	cond	policy
2.3	Number of lanes from parking garage	Number	1	1 is enough	cond	policy
2.4	Lane width of the lanes at the entrance	In meters	2.3	min, 2,4 recommended	cond	policy
2.5	Width of the island in the middle	In meters	0.8	min	cond	policy
2.6	Length of the island in the middle	In meters	5	min	cond	policy
2.7	The distance between ticket machine and land	In centimetres	15	abs	cond	policy
2.8	The distance between ticket machine and barrier	In meters	3	abs	cond	policy
2.9	Regulate the number of cars inside the parking garage	Number	245	max	cond	client
2.10	Ticket checker	Description	One at the exit in combination with barrier	-	reqmt	client
2.11	Number of ticket machines	Number	x	x	reqmt	client
2.12	The barrier	Description	One at the exit in combination with ticket check	-	reqmt	client
3.	**Parking spaces**					
3.1	The width of a parking space for 90° parking	In meters	2.5	min	cond	policy
3.2	The lane width for 90° parking with 2-way traffic	In meters	6	min	cond	policy
3.3	The lane width for 90° parking with one way traffic	In meters	5.66	min	cond	policy
3.4	The parking space depth for 90° parking	In meters	5.13	min	cond	policy

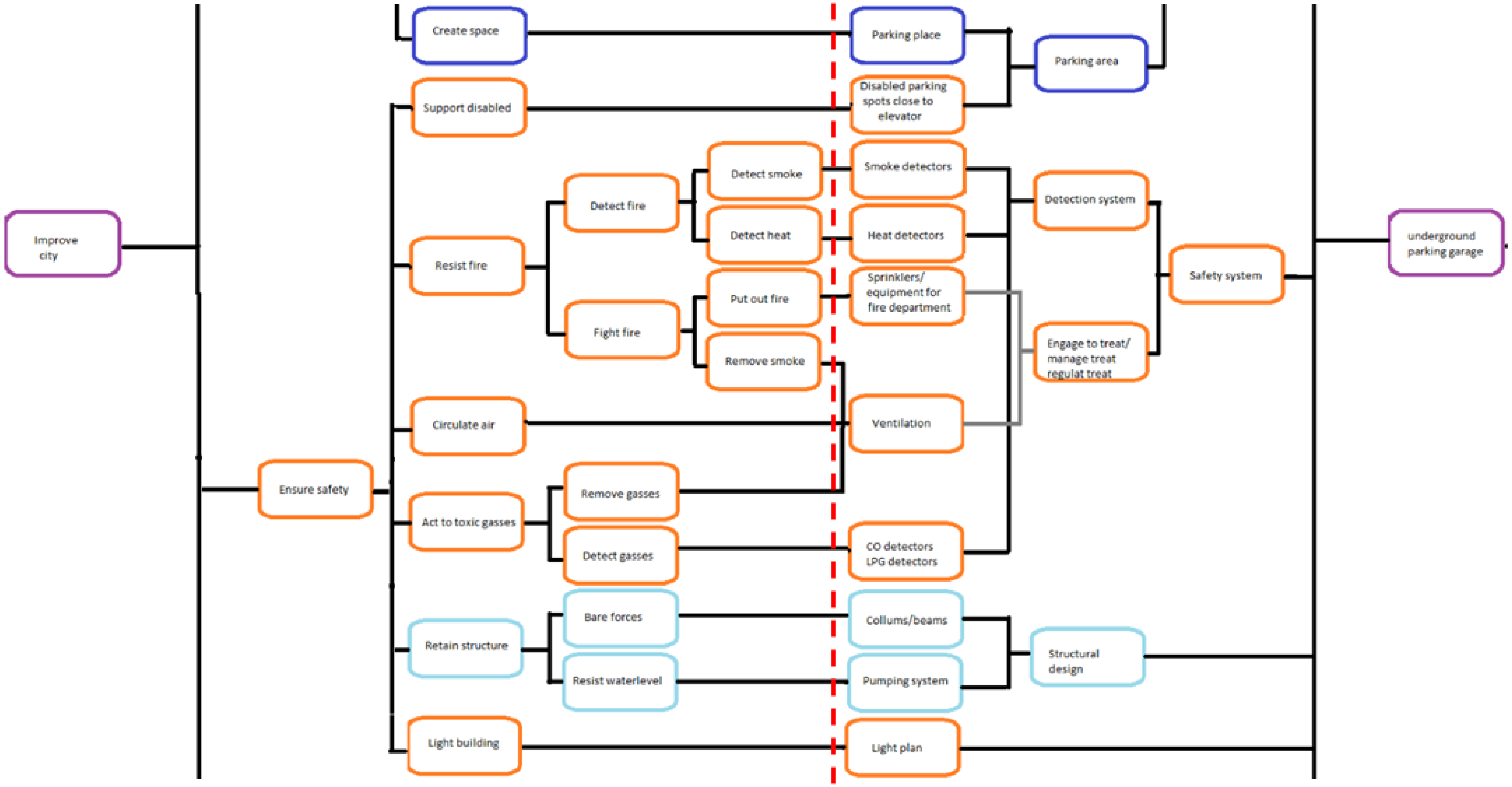
3.5	The parking space width for disabled for 90° parking	In meters	3.5	min	cond	policy
3.6	Width addition parking space caused by column (Between 0.5 and 1.5 m from lane) on 1 side	In centimetres	15	min	cond	policy
3.7	Width addition parking space caused by column (Between 0.5 and 1.5 m from lane) on 2 sides	In centimetres	35	min	cond	policy
3.8	Max size columns on corner parking space	In centimetres	20	max	cond	policy
3.9	The distance between disabled parking and elevator	In meters	50	max	cond	policy
4.	**Ramps in parking garage**					
4.1	The maximum slope of the ramp	Degrees	20	max	cond	policy
4.2	The maximum slope at horizontal levels	Degrees	3	max	cond	policy
4.3	Required distance between two ramps	In meters	7.5	min	cond	policy
4.4	The need of a superelevation ramp *(= overgangshelling)*	Slope a in degrees	when a>14°	condition	cond	policy
4.5	Length superelevation ramp top arch *(= topboog)* if a>14°	In meters	1,385 (half of the wheelbase)	min	cond	policy
4.6	Length superelevation ramp bottom arch (voetboog) if a>14°	In meters	2,77 (entire wheelbase)	min	cond	policy
4.7	Slope superelevation ramp	Degrees	0.5*slope main ramp	exact	cond	policy
4.8	Ceiling height at bottom arch when a>14°	In meters	2.3	min	cond	policy
4.9	Ceiling height at top arch when a>14°	In meters	2.3	min	cond	policy
4.10	Ceiling height bottom arch when a<14°	In meters	2.1	min	cond	policy
4.11	Ceiling height top arch when a<14°	In meters	2.2	min	cond	policy
4.12	Ceiling height parking garage	In meters	2.2	0.1	cond	policy
5.	**Elevators and stairs**					
5.1	Number of elevators necessary	Number	1	min	cond	policy
5.2	Number of elevators	Number	3	exact	reqmt	client
5.3	Capacity of elevators	Number	8	min	reqmt	client
5.4	Number of stairs	Number	3	exact	reqmt	client
5.5	Width stairs	In meters	1.2	min	reqmt	policy
5.6	Dimensions elevator	Length*width in meters	1,6x1,75	exact	reqmt	(Schindler, sd)

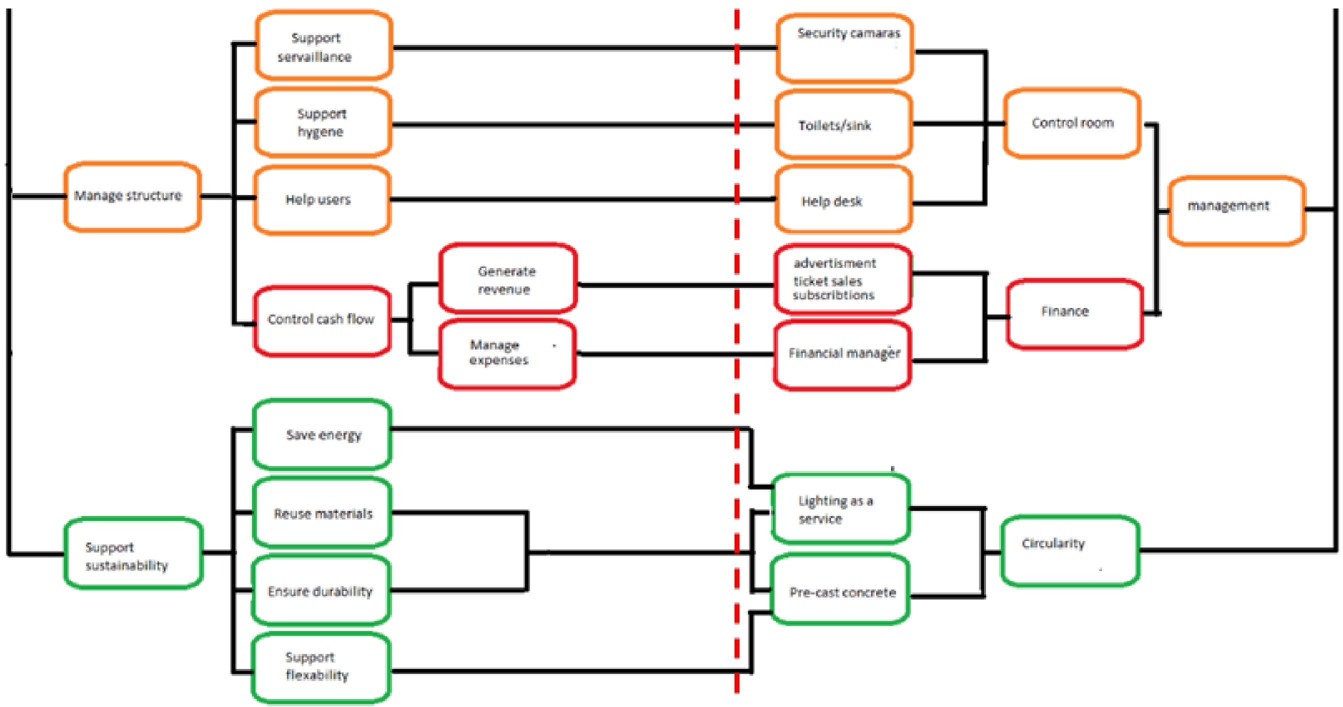
5.7	Dimensions stairs	Length*width in meters	x	exact	reqmt	policy
6.	**Stakeholder requirements**					
6.1	Capacity of spaces in the parking garage	Number	245	min	cond	client
6.2	Investment cost	In euros	7,283,702.95	800,000	cond	client
6.3	Storage units for all apartments	Number	331	exact	cond	client
6.4	Circular parts	Number	2	exact	cond	client
6.5	The net present value of the construction of the parking garage	Description	NPV should be positive	-	cond	client
7.	**Safety regulations**					
7.1	The amount of ventilation needed in the parking garage	dm^3/s per m^2 surface area	3	min	cond	policy
7.2	The range of a smoke detector	m^2	112	max	reqmt	(IFSEC Global, sd)
7.4	number of fire hoses within a certain area	number in m^2		max	reqmt	assumption
7.7	The range of the heat detectors	m^2	25.	max	reqmt	(IFSEC Global, sd)
7.8	Carbon monoxide detector range	m^2	400	max	cond	policy
7.9	Carbon monoxide detector (hang) height above floor level	m	1.5	max	cond	policy
7.10	Maximum carbon monoxide value in parking garage	mg/m^3	174	max	cond	policy
7.11	The range of the sprinklers in the parking garage	m^2	21.	max	reqmt	(Het CCV, sd)
7.12	Speed limit inside the parking garage	km/h	20.	max	reqmt	policy
7.13	Signage inside the parking garage	Description	Clear and understandable	-	cond	policy
7.14	Distance between columns	In meters	10.3	max	cond	policy
7.15	Water level	From ground level in meters	0.5	min	reqmt	(Gemeente Enschede, sd)
7.16	Maximum value LPG in parking garage	% LEL	20	max	cond	policy

7.17	The range of the LPG detectors	m^2	400	max	cond	policy
8.	**Control room**					
8.1	Surface area control room	in m^2	60	10	reqmt	client
8.2	Sanitary: toilets	number	2	min	reqmt	client
8.3	Sanitary: sink	number	1	min	reqmt	client
8.4	Space on the wall for surveillance equipment	in m^2	4	0.5	reqmt	client
8.5	There should be a place to ask questions	Description	easily findable	-	reqmt	client
8.6	Angular view of the surveillance cameras	degrees	92	max	reqmt	su
9.	**Lighting**					
9.1	Illumination intensity entrance and exit (daytime)	lux	200	min	reqmt	policy
9.2	Illumination intensity entrance and exit (night time)	lux	100	min	reqmt	policy
9.3	Illumination intensity lanes	lux	75	min	reqmt	policy
9.4	Illumination intensity Parking spaces	lux	75	min	reqmt	policy
9.5	Illumination intensity elevator and stairs	lux	100	min	reqmt	policy
9.6	Illumination intensity control room	lux	350	min	reqmt	policy
9.7	Potential saving energy by using light as a service	%	45	-	reqmt	client
10.	**General specifications parking garage**					
10.1	Number of floors	number	2	max	reqmt	group

B: FAST Diagram & Object Tree




Improve city
Ensure safety
Create space
Support disabled
Resist fire
Circulate air
Act to toxic gasses
Retain structure
Light building
Detect fire
Fight fire
Remove gasses
Detect gasses
Bare forces
Resist waterlevel
Detect smoke
Detect heat
Put out fire
Remove smoke
Parking place
Disabled parking spots close to elevator
Smoke detectors
Heat detectors
Sprinklers/ equipment for fire department
Ventilation
CO detectors LPG detectors
Collums/beams
Pumping system
Light plan
Parking area
Detection system
Engage to treat/ manage treat regulat treat
Safety system
Structural design
underground parking garage


Manage structure
Support servaillance
Support hygene
Help users
Control cash flow
Generate revenue
Manage expenses
Security camaras
Toilets/sink
Help desk
advertisment ticket sales subscribtions
Financial manager
Control room
Finance
management
Support sustainability
Save energy
Reuse materials
Ensure durability
Support flexability
Lighting as a service
Pre-cast concrete
Circularity

C: Requirements Allocation Sheet (RAS)

ID	Description	Function	R & F linked?	Object	F & O linked?
1.	**Storage unit**				
1.1	The storage unit should be spacious	Support workspace	OK	7,5 m^2 space	OK
1.2	There should be space for bikes	Store bicycles	OK	7,5 m^2 space	OK
1.3	There should be space for storage	Store goods	OK	Install shelves	OK
2.	**Entrance**				
2.1	The number of entrances into the parking garage for vehicles	Connect entrance	OK	Entrance to underground roundabout	OK
2.2	Number of lanes into parking garage	Regulate entrance	OK	Motorvehicle entrance	OK
2.3	Number of lanes from parking garage	Regulate entrance	OK	Motorvehicle entrance	OK
2.4	Lane width of the lanes at the entrance	Regulate entrance	OK	Motorvehicle entrance	OK
2.5	Width of the island in the middle	Regulate entrance	OK	Motorvehicle entrance	OK
2.6	Length of the island in the middle	Regulate entrance	OK	Motorvehicle entrance	OK
2.7	The distance between ticket machine and land	Regulate entrance	OK	Motorvehicle entrance	OK
2.8	The distance between ticket machine and barrier	Regulate entrance	OK	Motorvehicle entrance	OK
2.9	Regulate the number of cars inside the parking garage	Control amount	OK	Barrier with counter	OK
2.10	Ticket checker	Sell ticket	OK	Ticket checker	OK
2.11	Number of ticket machines	Check ticket	OK	Ticket machines	OK
2.12	Barriers at the entrance	Stop cars	OK	Barrier	OK
3.	**Parking spaces**				
3.1	The with of a parking space for 90° parking	Create space	OK	Parking places	OK
3.2	The lane width for 90° parking with 2-way traffic	Process traffic	OK	Lanes	OK
3.3	The lane width for 90° parking with one way traffic	Process traffic	OK	Lanes	OK
3.4	The parking space depth for 90° parking	Store cars	OK	Parking places	OK
3.5	The Parking space width for disabled for 90° parking	Store cars	OK	Parking places	OK
3.6	Width addition parking space caused by column (Between 0.5 and 1.5 m from lane) on 1 side	Store cars	OK	Parking places	OK

3.7	Width addition parking space caused by column (Between 0.5 and 1.5 m from lane) on 2 sides	Store cars	OK	Parking places	OK
3.8	Max size columns on corner parking space	Meet regulations	OK	NEN 2443:2013	OK
3.9	The distance between disabled parking and elevator	Support disabled	OK	Disabled parking right next to elevator	OK
4.	**Ramps in parking garage**				
4.1	The maximum slope of the ramp	Bridge height difference	OK	Ramp	OK
4.2	The maximum slope at horizontal levels	Bridge height difference	OK	Ramp	OK
4.3	Required distance between two ramps	Bridge height difference	OK	Ramp	OK
4.4	The need of a superelevation ramp *(= overgangshelling)*	Bridge height difference	OK	Ramp	OK
4.5	Length superelevation ramp top arch *(= topboog)* if a>14°	Bridge height difference	OK	Ramp	OK
4.6	Length superelevation ramp bottom arch *(= voetboog)* if a>14°	Bridge height difference	OK	Ramp	OK
4.7	Slope superelevation ramp	Bridge height difference	OK	Ramp	OK
4.8	Ceiling height at bottom arch when a>14°	Bridge height difference	OK	Ramp	OK
4.9	Ceiling height at top arch when a>14°	Bridge height difference	OK	Ramp	OK
4.10	Ceiling height bottom arch when a<14°	Bridge height difference	OK	Ramp	OK
4.11	Ceiling height top arch when a<14°	Bridge height difference	OK	Ramp	OK
4.12	Ceiling height parking garage	Bridge height difference	OK	Ramp	OK
5.	**Elevators and stairs**				
5.1	Number of elevators necessary	Reach building on top	OK	Stairs/lift	OK
5.2	Number of elevators	Reach building on top	OK	Stairs/lift	OK
5.3	Capacity of elevators	Reach building on top	OK	Stairs/lift	OK
5.4	Number of stairs	Reach building on top	OK	Stairs/lift	OK
5.5	Width stairs	Reach building on top	OK	Stairs/lift	OK
5.6	Dimensions elevator	Reach building on top	OK	Stairs/lift	OK
5.7	Dimensions stairs	Reach building on top	OK	Stairs/lift	OK
6.	**Stakeholder requirements**				
6.1	Capacity of spaces in the parking garage	Store cars	OK	Parking places	OK
6.2	Investment cost	Manage expenses	OK	Financial manager	OK
6.3	Storage units for all apartments	Store entities	OK	Storage unit	OK

6.4	Circular parts	Implement sustainability	OK	Circular Economy	OK
6.5	The net present value of the construction of the parking garage	Control cash flow	OK	Finance	OK
7.	**Safety regulations**				
7.1	The amount of ventilation needed in the parking garage	Circulate air/ remove smoke/toxic gasses	OK	Ventilation	OK
7.2	The range of a smoke detector	Detect smoke	OK	Smoke detection system	OK
7.4	Number of fire hoses within a certain area	Put out fire	OK	Fire hose connection point for the fire d.	OK
7.7	The range of a heat detector	Detect heat	OK	Heat detection system	OK
7.8	Carbon monoxide detector range	Detect gasses	OK	Carbon monoxide detection system	OK
7.9	Carbon monoxide detector (hang) height above floor level	Detect gasses	OK	Carbon monoxide detection system	OK
7.10	Maximum carbon monoxide value in parking garage	Detect gasses	OK	Carbon monoxide detection system	OK
7.11	The range of the sprinklers in the parking garage	Put out fire	OK	Sprinkler system	OK
7.12	Speed limit inside the parking garage	Control velocity	OK	Speed limit	OK
7.13	Signage inside the parking garage	Guide traffic	OK	Signage	OK
7.14	Distance between the columns	Bare forces	OK	Install columns	OK
7.15	Water level	Resist water level	OK	Install pumping system	OK
8.	**Control room**				
8.1	Surface area control room	Assure space	OK	45 m^2 space	OK
8.2	Sanitary: toilets	Support hygiene	OK	Toilets and sink	OK
8.3	Sanitary: sink	Support hygiene	OK	Toilets and sink	OK
8.4	Space on the wall for surveillance equipment	Support surveillance	OK	Space for big monitors	OK
8.5	There should be a place to ask questions	Help users	OK	Help desk	OK
8.6	Angular view of the surveillance cameras	Support surveillance	OK	Security cameras	OK
9.	**Human factors**				
9.1	Humidity in the parking garage	Control humidity	OK	Humidity system	OK
9.2	Temperature in the parking garage	Control temperature	OK	Heating system	OK
10.	**Lighting**				

10.1	Illumination intensity entrance and exit (daytime)	Light building	OK	Lighting plan	OK
10.2	Illumination intensity entrance and exit (night time)	Light building	OK	Lighting plan	OK
10.3	Illumination intensity lanes	Light building	OK	Lighting plan	OK
10.4	Illumination intensity Parking spaces	Light building	OK	Lighting plan	OK
10.5	Illumination intensity elevator and stairs	Light building	OK	Lighting plan	OK
10.6	Illumination intensity Control room	Light building	OK	Lighting plan	OK
10.7	Potential saving energy by using light as a service	Save energy	OK	Lighting as a service	OK
11	**General specifications parking garage**				
11.1	Number of floors	Does not apply	-	Does not apply	-

D: Design Synthesis

D.1 Lighting plan

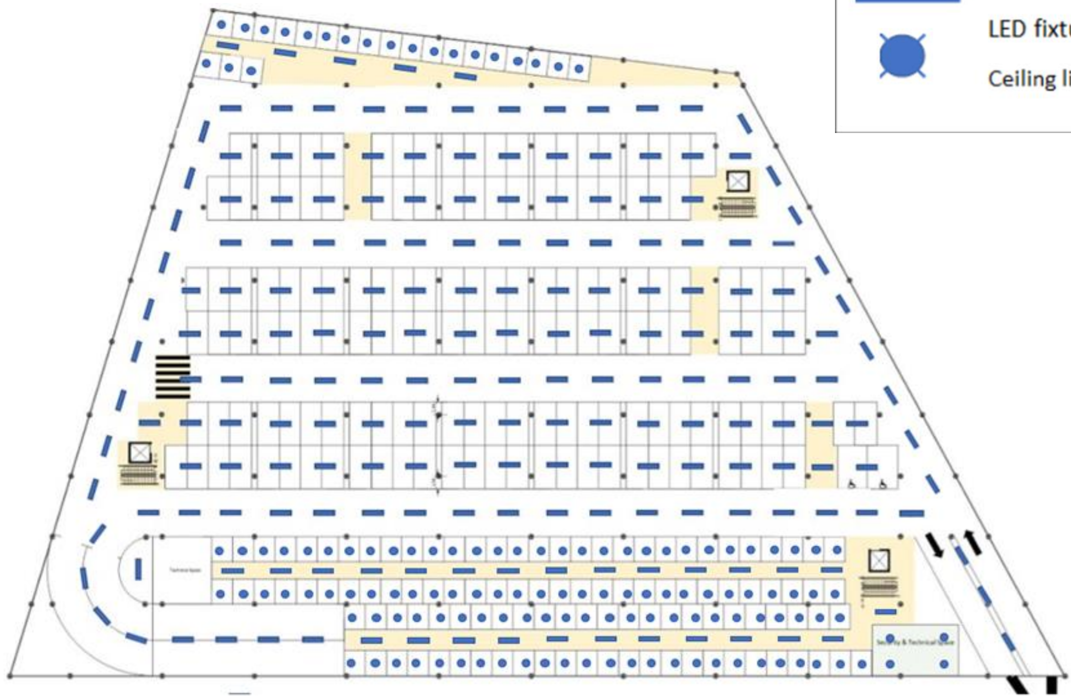


Figure 20: Lighting plan floor -1

Figure 21: Lighting plan floor -2

D.2 Ventilation plan

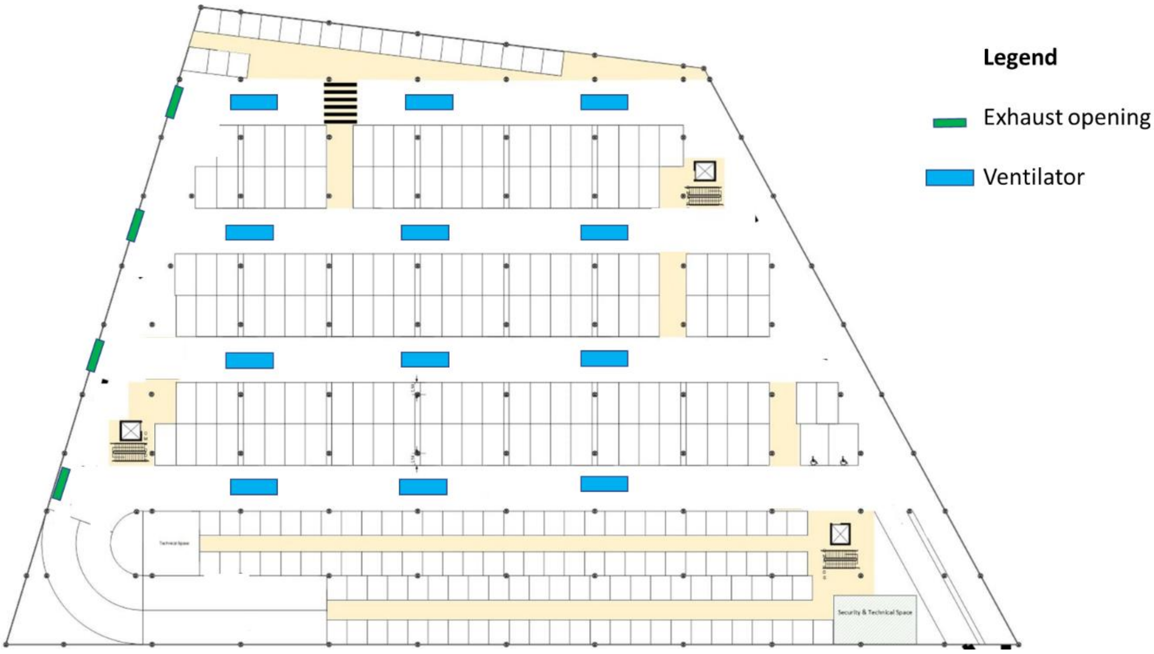


Figure 22: Ventilation plan floor -1

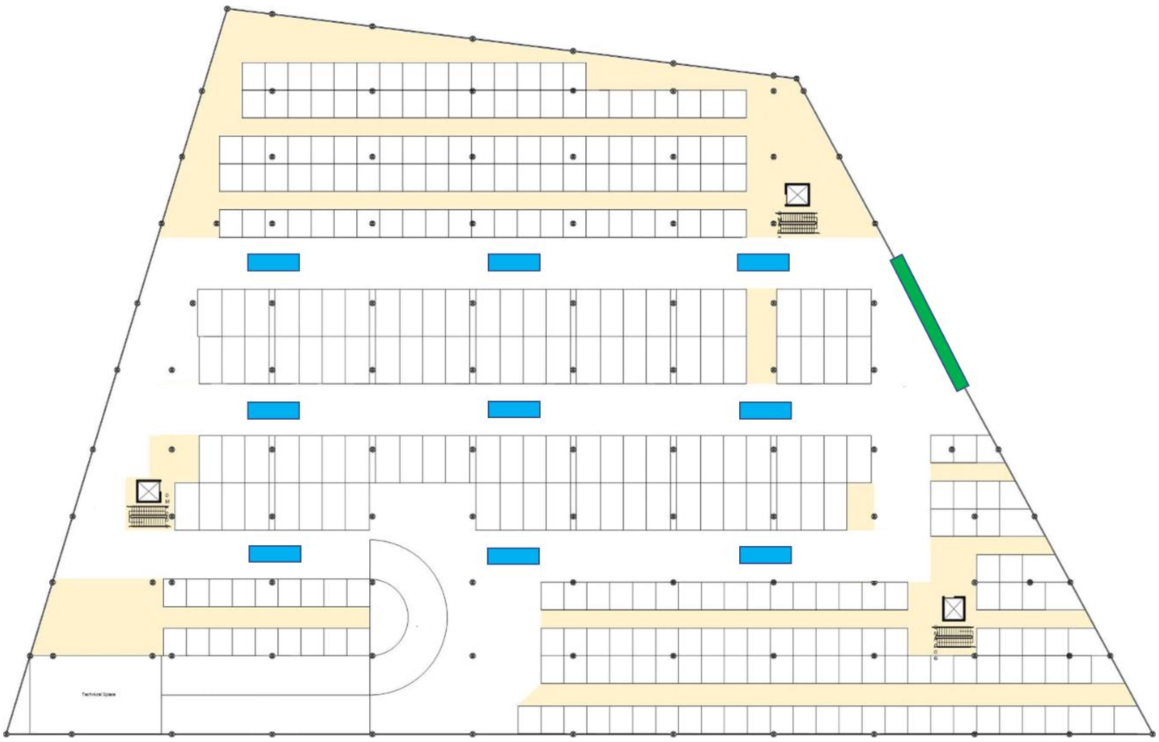


Figure 23: Ventilation plan floor -2

D.3 Security plan

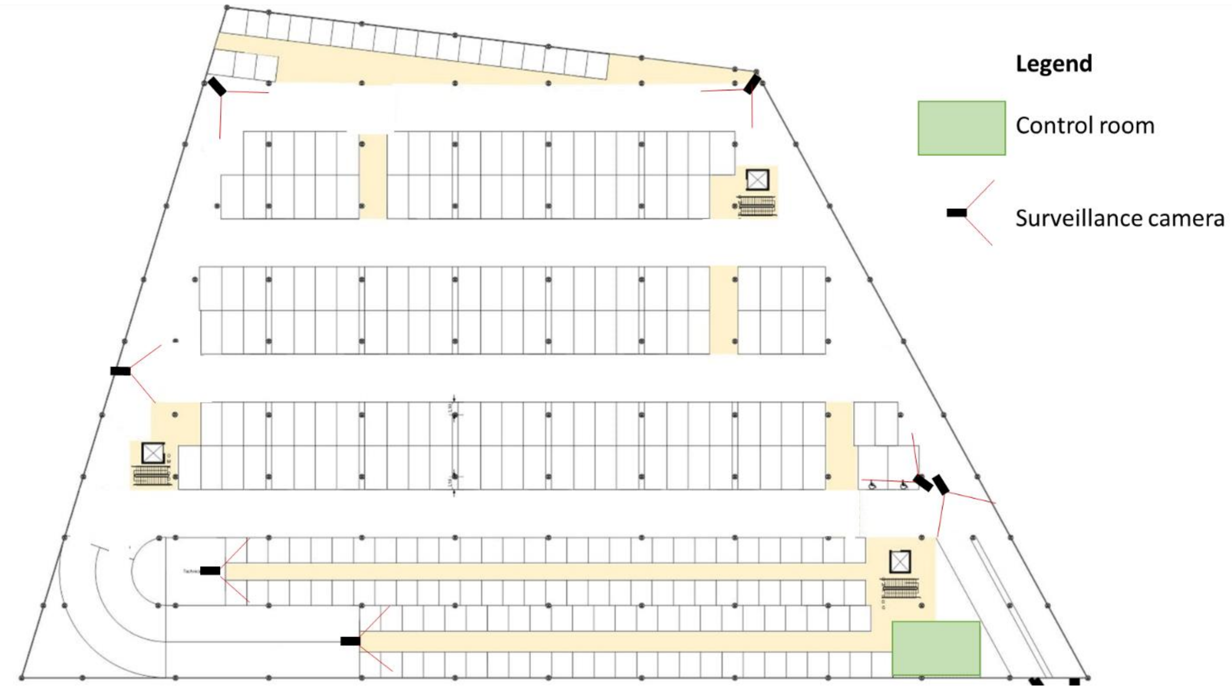


Figure 24: Security plan floor -1

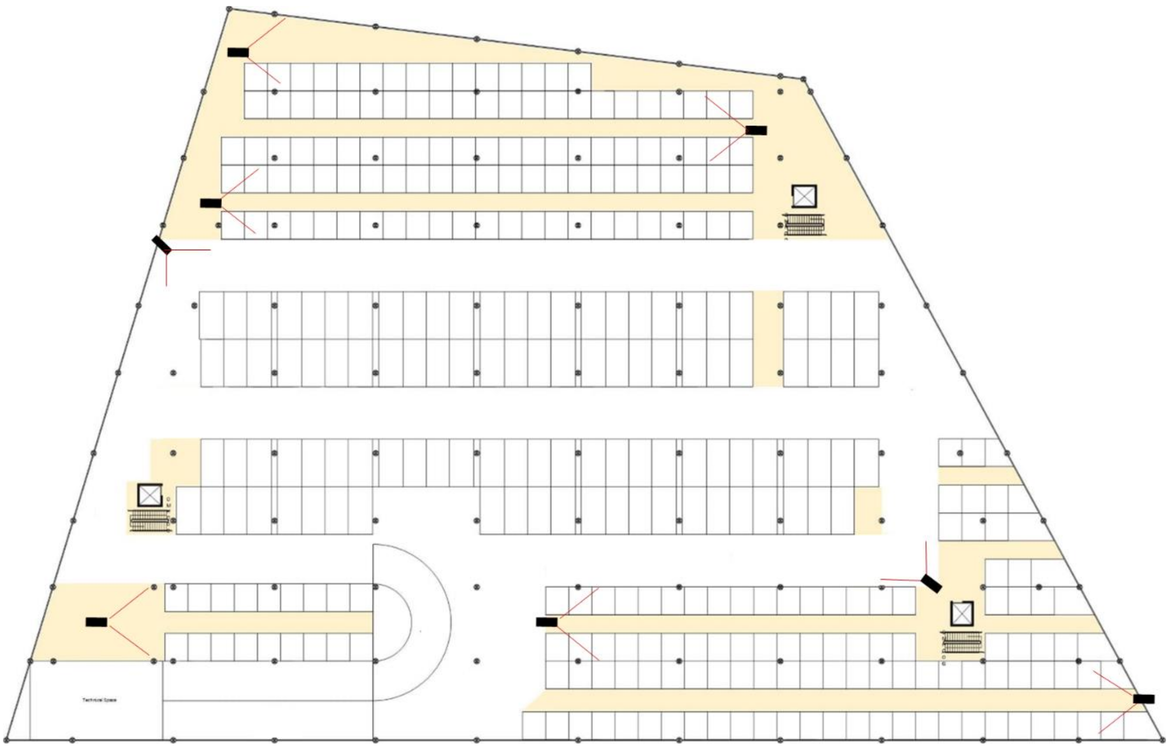


Figure 25: Security plan floor -2

D.4 Safety plan

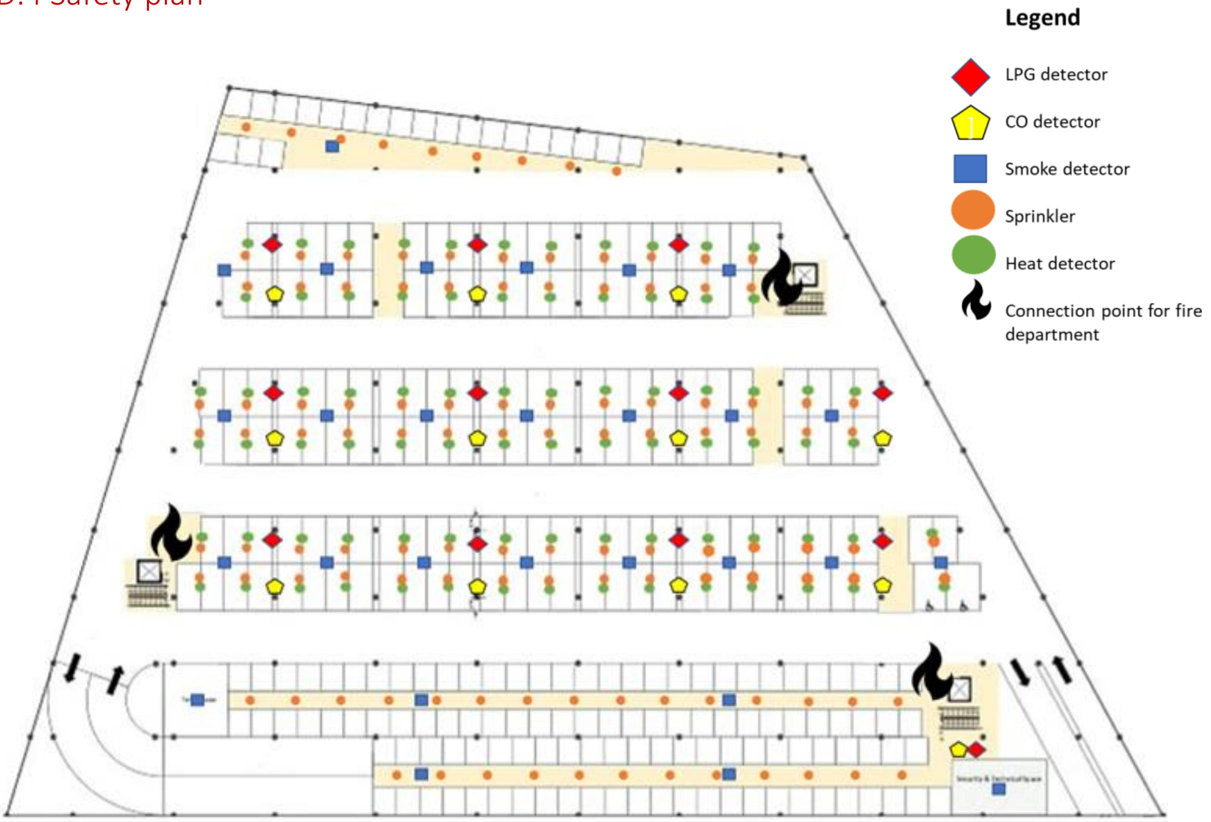


Figure 26: Safety plan floor -1

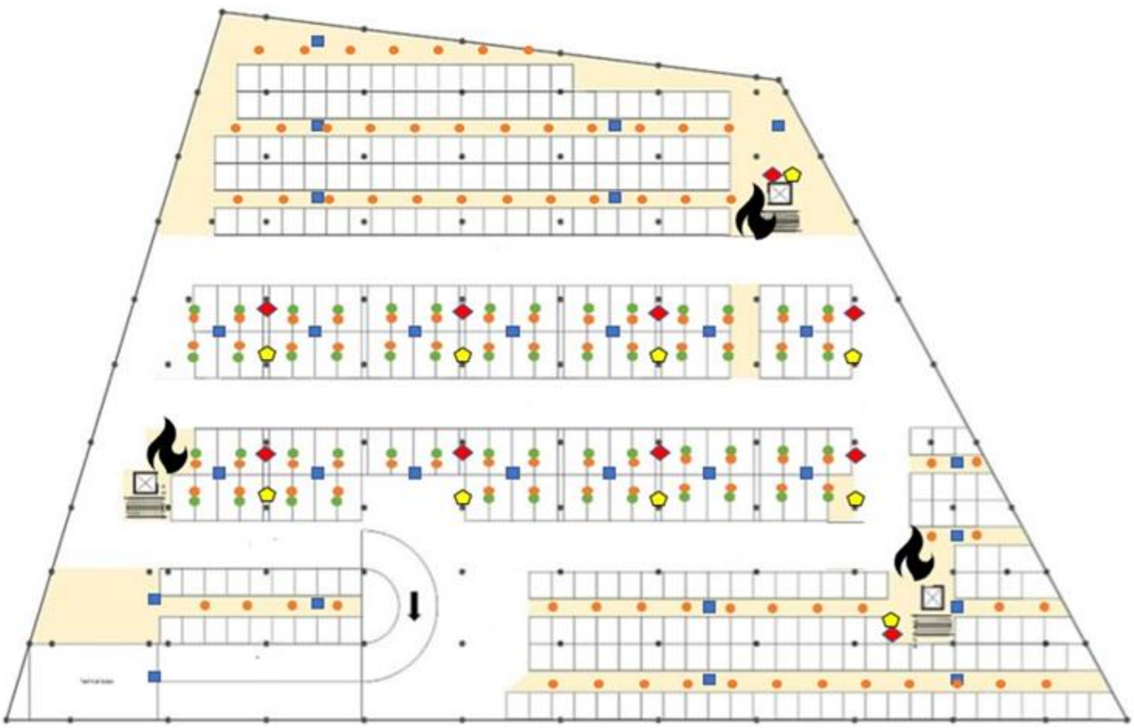


Figure 27: Safety plan floor -2

E: Verification matrix

		Design verification during design phase				Design verification after realisation phase			
ID	**Description**	**When**	**Who**	**How**	**Result**	**When**	**Who**	**How**	**Result**
1.	**Storage unit**								
1.1	The storage unit should be spacious	after p. design loop	group	analysis	OK	after construction storage units	builder	analysis	
1.2	There should be space for bikes	after p. design loop	group	analysis	OK	after construction storage units	builder	analysis	
1.3	There should be space for storage	after p. design loop	group	analysis	OK	after construction storage units	builder	analysis	
2.	**Entrance**								
2.1	The number of entrances into the parking garage for vehicles	after conceptual design loop	group	inspection	OK	after construction entrance	builder	inspection	
2.2	Number of lanes into parking garage	after conceptual design loop	group	inspection	OK	after construction entrance	builder	inspection	
2.3	Number of lanes from parking garage	after conceptual design loop	group	inspection	OK	after construction entrance	builder	inspection	
2.4	Lane width of the lanes at the entrance	after p. design loop	group	inspection	OK	after construction entrance	builder	inspection	
2.5	Width of the island in the middle	after p. design loop	group	inspection	OK	after construction entrance	builder	inspection	

2.6	Length of the island in the middle	after p. design loop	group	inspection	OK	after construction entrance	builder	inspection	
2.7	The distance between ticket machine and land	after p. design loop	group	inspection	OK	after construction entrance	builder	inspection	
2.8	The distance between ticket machine and barrier	after p. design loop	group	inspection	OK	after construction entrance	builder	inspection	
2.9	Regulate the number of cars inside the parking garage	after p. design loop	group	inspection	OK	after construction entrance	builder	simulation	
2.10	Ticket checker	after p. design loop	group	inspection	OK	after construction entrance	builder	simulation	
2.11	Number of ticket machines	after p. design loop	group	inspection	OK	after construction entrance	builder	inspection	
2.12	The barrier	after p. design loop	group	inspection	OK	after construction entrance	builder	simulation	
3.	**Parking spaces**								
3.1	The width of a parking space for 90° parking	after p. design loop	group	inspection	OK	after construction parking area	builder	inspection	
3.2	The lane width for 90° parking with 2-way traffic	after p. design loop	group	inspection	OK	after construction parking area	builder	inspection	
3.3	The lane width for 90° parking with one way traffic	after p. design loop	group	inspection	OK	after construction parking area	builder	inspection	

3.4	The parking space depth for 90̊ parking	after p. design loop	group	inspection	OK	after construction parking area	builder	inspection	
3.5	The Parking space width for disabled for 90̊ parking	after p. design loop	group	inspection	OK	after construction parking area	builder	inspection	
3.6	Width addition parking space caused by column (Between 0.5 and 1.5 m from lane) on 1 side	after p. design loop	group	inspection	OK	after construction parking area	builder	inspection	
3.7	Width addition parking space caused by column (Between 0.5 and 1.5 m from lane) on 2 sides	after p. design loop	group	inspection	OK	after construction parking area	builder	inspection	
3.8	Max size columns on corner parking space	after p. design loop	group	inspection	OK	after construction parking area	builder	inspection	
3.9	The distance between disabled parking and elevator	after p. design loop	group	inspection	OK	after construction parking area	builder	inspection	
4.	**Ramps in parking garage**								
4.1	The maximum slope of the ramp	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.2	The maximum slope at horizontal levels	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.3	Required distance between two ramps	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.4	The need of a superelevation ramp *(= overgangshelling)*	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	

4.5	Length superelevation ramp top arch *(= topboog)* if a>14°	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.6	Length superelevation ramp bottom arch *(= voetboog)* if a>14°	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.7	Slope superelevation ramp	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.8	Ceiling height at bottom arch when a>14°	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.9	Ceiling height at top arch when a>14°	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.10	Ceiling height bottom arch when a<14°	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.11	Ceiling height top arch when a<14°	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
4.12	Ceiling height parking garage	after p. design loop	group	inspection	OK	after construction ramp	builder	inspection	
5.	**Elevators and stairs**								
5.1	Number of elevators necessary	after p. design loop	group	inspection	OK	after construction elevator	builder	inspection	
5.2	Number of elevators	after p. design loop	group	inspection	OK	after construction elevator	builder	inspection	

5.3	Capacity of elevators	after p. design loop	group	product informatio n	OK	after construction elevator	builder	product informatio n	
5.4	Number of stairs	after p. design loop	group	inspection	OK	after construction stairs	builder	inspection	
5.5	Width stairs	after p. design loop	group	inspection	OK	after construction stairs	builder	inspection	
5.6	Dimensions elevator	after p. design loop	group	product informatio n	OK	after construction elevator	builder	product informatio n	
5.7	Dimensions stairs	after p. design loop	group	inspection	OK	after construction stairs	builder	inspection	
6.	**Stakeholder requirements**								
6.1	Capacity of spaces in the parking garage	after p. design loop	group	analysis	OK	after construction parking area	builder	inspection	
6.2	Investment cost	after p. design loop	group	analysis	OK	during the exploitation phase	financina l manager	analysis	
6.3	Storage units for all apartments	after p. design loop	group	analysis	OK	after construction	builder	inspection	
6.4	Circular parts	after p. design loop	group	analysis	OK	after construction	builder	analysis	
6.5	The net present value of the construction of the parking garage	after p. design loop	group	analysis	OK	during the exploitation phase	Financial manager	analysis	
7.	**Safety regulations**								
7.1	The amount of ventilation needed in the parking garage	after p. design loop	group	analysis		after construction ventilation	builder	simulation	

7.2	The range of a smoke detector	after p. design loop	group	product informatio n	OK	after construction	builder	simulation	
7.3	Number of fire hoses within a certain area	after p. design loop	group	analysis	OK		builder	analysis	
7.4	The range of the heat detectors	after p. design loop	group	product informatio n	OK	after installation	builder	simulation	
7.5	Carbon monoxide detector range	after p. design loop	group	product informatio n	OK	after installation	builder	simulation	
7.6	Carbon monoxide detector (hang) height above floor level	after p. design loop	group	analysis	OK	after installation	builder	inspection	
7.7	Maximum carbon monoxide value in parking garage	after p. design loop	group	analysis	OK	after installation	builder	analysis	
7.8	The range of the sprinklers in the parking garage	after p. design loop	group	product informatio n	OK	after installation	builder	simulation	
7.9	Speed limit inside the parking garage	after p. design loop	group	analysis	OK	after opening	builder	inspection	
7.10	Signage inside the parking garage	after p. design loop	group	benchmark	OK	after commissionin g	builder	inspection	
7.11	Distance between columns	after p. design loop	group	benchmark	OK	after construction	builder	inspection	
7.12	Water level	after p. design loop	group		OK		builder		
7.13	Maximum value LPG in parking garage	after p. design loop	group	analysis	OK	after installation	builder	analysis	
7.14	The range of the LPG detectors	after p. design loop	group	product informatio n	OK	after installation	builder	simulation	
8.	**Control room**								

8.1	Surface area control room	after p. design loop	group	analysis	OK	after construction	builder	analysis	
8.2	Sanitary: toilets	after p. design loop	group	inspection	OK	after installation	builder	simulation	
8.3	Sanitary: sink	after p. design loop	group	inspection	OK	after installation	builder	simulation	
8.4	Space on the wall for surveillance equipment	after p. design loop	group	inspection	OK	after construction	builder	inspection	
8.5	Angular view of the surveillance camera's	after p. design loop	group	product informatio n	OK	after installation	builder	product informatio n	
8.6	There should be a place to ask questions	after p. design loop	group	inspection	OK	after construction	builder	inspection	
9.	**Human factors**								
9.1	Humidity in the parking garage	after p. design loop	group	analysis	OK	after commissionin g	builder	inspection	
9.2	Temperature in the parking garage	after p. design loop	group	analysis	OK	after commissionin g	builder	inspection	
10.	**Lighting**								
10.1	Illumination intensity entrance and exit (daytime)	after p. design loop	group	analysis	OK	after installation	builder	inspection	
10.2	Illumination intensity entrance and exit (night time)	after p. design loop	group	analysis	OK	after installation	builder	inspection	
10.3	Illumination intensity lanes	after p. design loop	group	analysis	OK	after installation	builder	inspection	
10.4	Illumination intensity parking spaces	after p. design loop	group	analysis	OK	after installation	builder	inspection	
10.5	Illumination intensity elevator and stairs	after p. design loop	group	analysis	OK	after installation	builder	inspection	
10.6	Illumination intensity control room	after p. design loop	group	analysis	OK	after installation	builder	inspection	

10.7	Potential saving energy by using light as a service	after p. design loop	group	analysis	OK	after installation	builder	inspection	
11.	**General specifications parking garage**								
11.1	Number of floors	after conceptual loop	group		OK		group		

F: Structural Design

Assumptions

According to 'Principles of Geotechnical Engineering' by Braja M. Das and Khaled Sobhan page 68 γ_{dry} of dense uniform sand is 18 kN/m^3. Therefore, the assumption is made that the whole ground of the parking garage area will consist of dense uniform sand.

In examples in the lectures of Structural Mechanics of G. Snellink, there were a few examples when there has been made use of $\gamma_{dry} = 18\ kN/m^3$. In those examples the γ_{sat} was 21 kN/m^3. Therefore, the assumption is made that $\gamma_{sat} = 21\ kN/m^3$.

The angle of internal friction is the maximum angle of inclination under which granular material does not shift. In this case there will be sand. For sand the angle of internal friction is between 27 and 37 degrees (Snellink, 2019). The assumption is made that the angle will be 30 degrees. This assumption is made because the calculation will be easier because of the outcome of the calculation of K_a and K_p.

Division in the ground

In *Figure 28* below the division between the different layers in the parking garage can be seen. From *Figure 28* can be made and from that the calculation of the sheet pile.

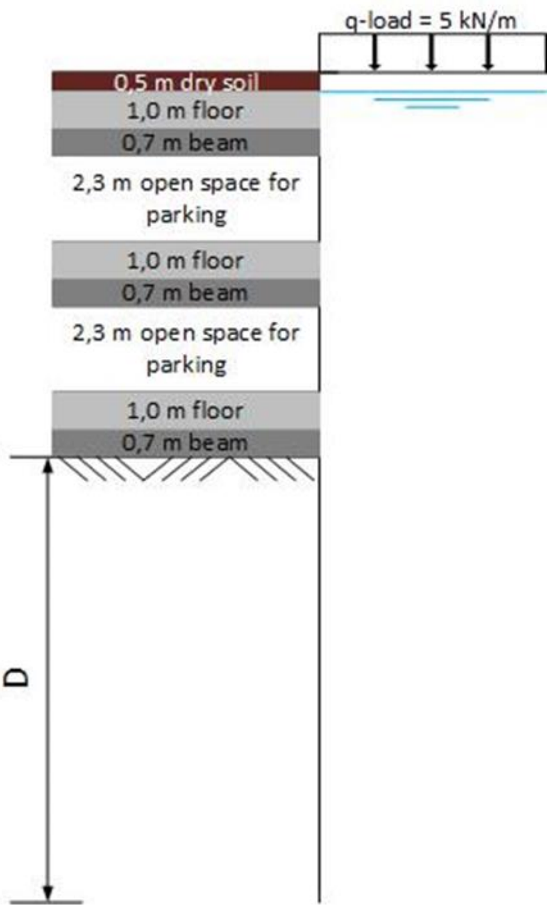


Figure 28: Division between different layers in the garage

Calculations of sheet pile

For the calculations of 3 till 6, there are different formulas used but in the calculation itself the same formula is used. Therefore, in each calculation the first calculation is from point 1 or A. This will serve as an example of a fully worked out calculation. After that a table is shown which will indicate the location of the point, the knowns, calculation and the answer of the calculation.

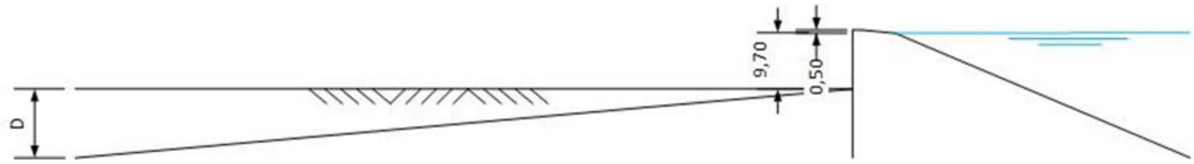


Figure 29: Overview sheet piles (dimensions in meters)

Figure 29 is not on scale. This is done because otherwise the situation is not clear. As there can be seen is the left line (of the ground pressure) is very large. If this was done on scale, the small turn is not visible. To make it for the calculations more clear *Figure 30* is used. In this figure the system can be split up in different areas. With those areas the calculations are done.

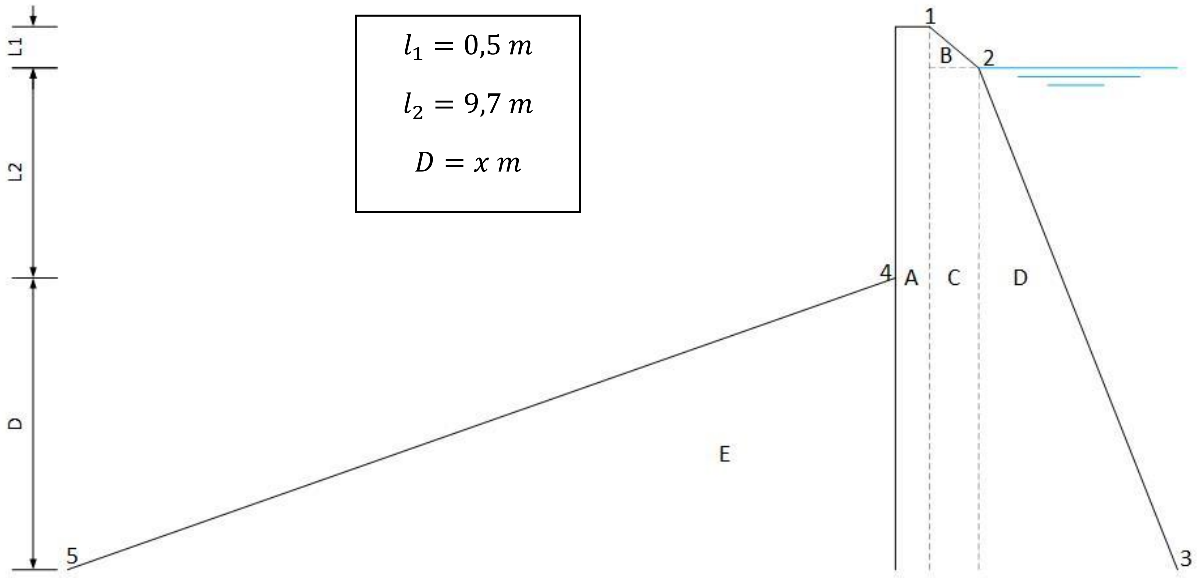


Figure 30: Overview sheet piles for calculations

Calculation 1: Active & passive pressure

$$K_a = tan^2(45 - \frac{\varphi}{2})$$

$$K_p = tan^2(45 + \frac{\varphi}{2})$$

Where:

$\varphi = 30°$

This results in:

$$K_a = tan^2(45 - \frac{30}{2})$$

$$K_p = tan^2(45 + \frac{30}{2})$$

Which gives:

$$K_a = {}^1/_3$$

$$K_p = 3$$

Calculation 2: Vertical soil forces

Point 1

$$\sigma_{v,1} = q - load\ which\ is\ given$$

$$\sigma_{v,1} = 5\ kN/m^2$$

Point 2

$$\sigma_{v,2} = \sigma_{v,1} + l_1 * \gamma_{dry}$$

Where:

$\sigma_{v,2} = 5\ kN/m^2$

$l_1 = 0{,}5\ m$

$\gamma_{dry} = 18\ kN/m^3$

This results in:

$$\sigma_{v,2} = 5 + 0{,}5 * 18$$

Which gives:

$$\sigma_{v,2} = 14\ kN/m^2$$

Point 3

$$\sigma_{v,3} = \sigma_{v,2} + (l_2 + D) * \gamma'$$

Where:

$\sigma_{v,2} = 14\ kN/m^2$

$l_2 = 10{,}2\ m$

$D = x\ m$

$\gamma' = \gamma_{sat} - \gamma_{wat} = 21 - 10 = 11\ kN/m^3$

This results in:

$$\sigma_{v,3} = 14 + (10{,}2 + x) * 11$$

Which gives:

$$\sigma_{v,3} = 126{,}2 + 11x\ kN/m^2$$

Point 4

The assumption is made that there is nothing above the ground at the left side of the sheet pile and thus will there be the pressure zero.

$$\sigma_{v,4} = 0\ kN/m^2$$

Point 5

$$\sigma_{v,5} = \gamma_{wat} * D$$

Where:

$\gamma_{wat} = 10\ kN/m^3$

$D = x\ m$

Which gives:

$$\sigma_{v,5} = 10x\ kN/m^2$$

Calculation 3: Horizontal soil forces

The horizontal soil forces can be calculated with the same formula all the time.

$$\sigma_h = \sigma_v * K$$

When calculating $\sigma_{h,1}$ the $\sigma_{v,1}$, which is calculated above, will be used. The only thing that needs a bit of attention is the active and passive pressure and thus on which side of the sheet pile the calculation is made. The left side is passive pressure and the right side is active pressure in our situation.

Point 1

$$\sigma_{h,1} = \sigma_{v,1} * K_a$$

Where:

$\sigma_{v,1} = 5\ kN/m^2$

$K_a = \frac{1}{3}$

This results in:

$$\sigma_{h,1} = 5 * \frac{1}{3}$$

Which gives:

$$\sigma_{h,1} = \frac{5}{3}\ kN/m^2$$

Location	Knowns	Calculation	Outcome
Point 1	$\sigma_{v,1} = 5\ kN/m^2$ $K_a = \frac{1}{3}$	$\sigma_{h,1} = 5 * \frac{1}{3}$	$\sigma_{h,1} = \frac{5}{3}\ kN/m^2$
Point 2	$\sigma_{v,2} = 14\ kN/m^2$ $K_a = \frac{1}{3}$	$\sigma_{h,2} = 14 * \frac{1}{3}$	$\sigma_{h,2} = \frac{14}{3}\ kN/m^2$
Point 3	$\sigma_{v,3} = 126{,}2 + 11x\ kN/m^2$ $K_a = \frac{1}{3}$	$\sigma_{h,3} = (126{,}2 + 11x) * \frac{1}{3}$	$\sigma_{h,3} = 42\frac{1}{15} + \frac{11}{3}x\ kN/m^2$
Point 4	$\sigma_{v,4} = 0\ kN/m^2$ $K_p = 3$	$\sigma_{h,4} = 0 * 3$	$\sigma_{h,4} = 0\ kN/m^2$
Point 5	$\sigma_{v,5} = 10x\ kN/m^2$ $K_p = 3$	$\sigma_{h,5} = 10x * 3$	$\sigma_{h,5} = 30x\ kN/m^2$

Calculation 4: Forces

All the calculations to determine the forces of the structure can be done with the same formula. All the knowns in this formula are calculated or determined in the previous calculations.

$$F = factor * h * \sigma_h$$

Point A

$$F_A = factor * h_A * \sigma_{h,1}$$

Where:

$factor = 1$

$h_A = 11{,}9 + x\ m$

$\sigma_{h,1} = \frac{5}{3}\ kN/m^2$

This results in:

$$F_A = (11{,}9 + x) * \frac{5}{3}$$

Which gives:

$$F_A = 19\frac{5}{6} + \frac{5}{3}x\ kN/m$$

Location	Knowns	Calculation	Outcome
Point A	$factor = 1$ $h_A = 11{,}9 + x\ m$ $\sigma_{h,1} = \frac{5}{3}\ kN/m^2$	$F_A = (11{,}9 + x) * \frac{5}{3}$	$F_A = 19\frac{5}{6} + \frac{5}{3}x\ kN/m$
Point B	$factor = \frac{1}{2}$ $h_B = 0{,}5\ m$ $\sigma_{h,2} = 3\ kN/m^2$	$F_B = \frac{1}{2} * 0{,}5 * 3$	$F_B = 0{,}75\ kN/m$
Point C	$factor = 1$ $h_C = 11{,}4 + x\ m$ $\sigma_{h,3} = 3\ kN/m^2$	$F_C = 1 * (11{,}4 + x) * 3$	$F_C = 34{,}2 + 3x\ kN/m$
Point D	$factor = \frac{1}{2}$ $h_D = 11{,}4 + x\ m$ $\sigma_{h,4} = 41{,}8 + \frac{11}{3}x\ kN/m^2$	$F_D = \frac{1}{2} * (11{,}4 + x)(41{,}8 + \frac{11}{3}x)$	$F_D = 238{,}26 + 41{,}8 + 1\frac{5}{6}x^2\ kN/m$
Point E	$factor = \frac{1}{2}$ $h_E = x\ m$ $\sigma_{h,5} = 30x\ kN/m^2$	$F_E = \frac{1}{2} * x * 30x$	$F_E = 15x^2\ kN/m$

Calculation 5: Centre of mass

The centre of mass can be calculated by using the same formula by making use of the good factor of each shape. A rectangular shape has a factor of an half and for a triangle the factor is a third.

$$z = factor * width$$

Point A

$$z_A = factor * w_A$$

Where:

$factor = \frac{1}{2}$

$w_A = 0{,}5 + 9{,}7 + x\ m$

This results in:

$$z_A = \frac{1}{2} * (0{,}5 + 9{,}7 + x)$$

Which gives:

$$z_A = 5{,}1 + \frac{1}{2}x\ m$$

Location	Knowns	Calculation	Outcome
Point A	$factor = \frac{1}{2}$ $w_A = 0,5 + 9,7 + x\ m$	$z_A = \frac{1}{2} * (0,5 + 9,7 + x)$	$z_A = 5,1 + \frac{1}{2} x\ m$
Point B	$factor = \frac{1}{3}$ $w_B = 0,5 + 9,7 + x\ m$	$z_B = \frac{1}{3} * (0,5 + 9,7 + x)$	$z_B = 3,4 + \frac{1}{3} x\ m$
Point C	$factor = \frac{1}{2}$ $w_C = 9,7 + x\ m$	$z_C = \frac{1}{2} * (9,7 + x)$	$z_C = 4,85 + \frac{1}{2} x\ m$
Point D	$factor = \frac{1}{3}$ $w_D = 9,7 + x\ m$	$z_D = \frac{1}{3} * (9,7 + x)$	$z_D = 3\frac{7}{30} + \frac{1}{3} x\ m$
Point E	$factor = \frac{1}{3}$ $w_E = x\ m$	$z_E = \frac{1}{3} * x$	$z_E = \frac{1}{3} x\ m$

Calculation 6: Moment

The moment in this situation can be calculated with the following formula:

$$M = F * z$$

In which F is the force and z is the arm of that force.

Point A

$$M_A = F_A * z_A$$

In which:

$F_A = 19\frac{5}{6} + \frac{5}{3} x\ kN/m$

$z_A = 5,1 + \frac{1}{2} x\ m$

This results in:

$$M_A = \left(19\frac{5}{6} + \frac{5}{3} x\right) * \left(5,1 + \frac{1}{2} x\right)$$

Which gives:

$$M_A = 101,15 + 18\frac{5}{12} x + \frac{5}{6} x^2\ kNm$$

Location	Knowns	Calculation	Outcome
Point A	$F_A = 19\frac{5}{6} + \frac{5}{3}x\ kN/m$ $z_A = 5{,}1 + \frac{1}{2}x\ m$	$M_A = (19\frac{5}{6} + \frac{5}{3}x) * (5{,}1 + \frac{1}{2}x)$	$M_A = 101{,}15 + 18\frac{5}{12}x + \frac{5}{6}x^2\ kNm$
Point B	$F_B = 0{,}75\ kN/m$ $z_B = 3{,}4 + \frac{1}{3}x\ m$	$M_B = 0{,}75 * (3{,}4 + \frac{1}{3}x)$	$M_B = 2{,}55 + 0{,}25x\ kNm$
Point C	$F_C = 34{,}2 + 3x\ kN/m$ $z_C = 4{,}85 + \frac{1}{2}x\ m$	$M_C = (34{,}2 + 3x) * (4{,}85 + \frac{1}{2}x)$	$M_C = 165{,}87 + 31{,}65x + 1{,}5x^2\ kNm$
Point D	$F_D = 238{,}26 + 41{,}8x + 1\frac{5}{6}x^2\ kN/m$ $z_D = 3\frac{7}{30} + \frac{1}{3}x\ m$	$M_D = (238{,}26 + 41{,}8x + 1\frac{5}{6}x^2) + (3\frac{7}{30} + \frac{1}{3}x)$	$M_D = 770{,}374 + 214\frac{43}{75}x + 19\frac{31}{36}x^2 + \frac{11}{18}x^3\ kNm$
Point E	$F_E = 15x^2\ kN/m$ $z_E = \frac{1}{3}x\ m$	$M_E = 15x^2 * \frac{1}{3}x$	$M_E = 5x^3\ kNm$

Calculation 7: Length of sheet pile

To calculate the total length of the sheet pile, the total moment should be zero. Therefore, the following formula is used:

$$\sum M(x) = 0$$

When applying this formula, the following calculation will be done:

$$\sum M = M_A + M_B + M_C + M_D - M_E$$

This sum should be equal to zero. When this is applied and filled in into a graphical calculator, the value of x = 11,842… m.

This value of x is only the length of D in the overview (*Figure 28*) Therefore, the total length of the sheet pile is 11,842… + 10,2 = 22,04 meters.

	factor	h (m)	σ_h (m)	F (kN/m)	z (m)	M (kNm)
A	1	11,9 + x	5/3	19 5/6 + 5/3x	5,1 + 1/2x	101,15 + 18 5/12x + 5/6x^2
B	0,5	0,5	3	0,75	3,4 + 1/3x	2,55 + 0,25x
C	1	11,4 + x	3	34,2 + 3x	4,85 + 1/2x	165,87 + 31,65x + 1,5x^2
D	0,5	11,4 + x	41,8 + 11/3x	238,26 + 41,8x + 1 5/6x^2	3 7/30 + 1/3x	770,374 + 214 43/75x + 19 31/36x^2 + 11/18x^3
E	0,5	x	30x	15x^2	1/3x	5x^3

Calculations of forces of beams

Current system

When a combination of *Figure 28* and *Figure 29/30* is made the following figure will be the result:

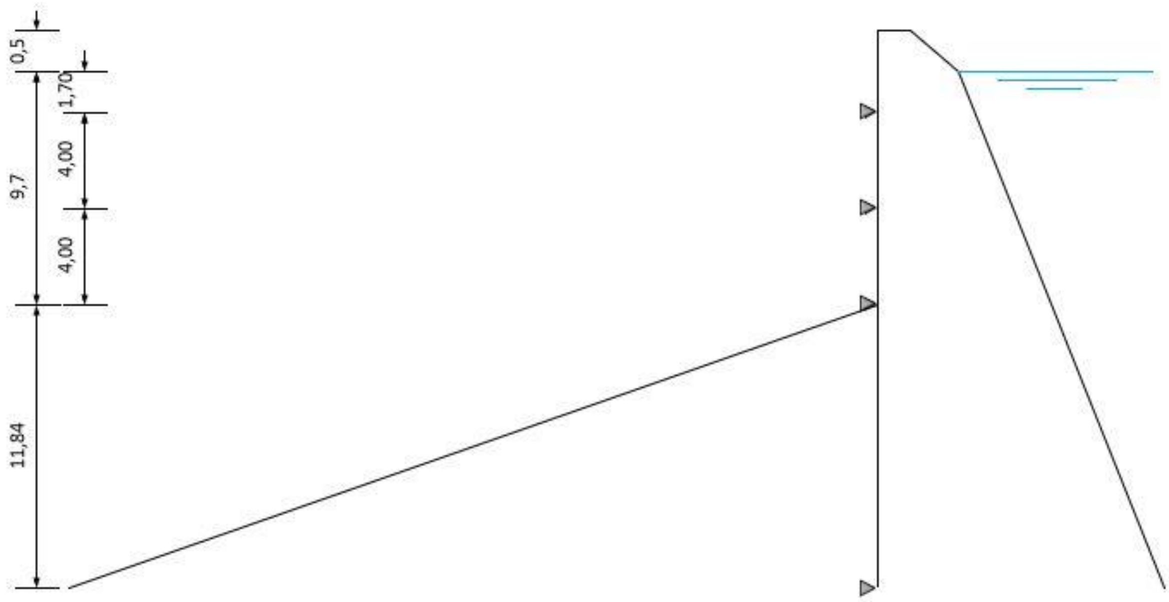


Figure 31: Locations of hinges on sheet pile

The triangles, which can be seen on the sheet pile, are the bottom of the beams. When the location of those triangles are known, the fixed end moments can be calculated.

Figure 31 can be translated into a system with a load in kN/m^2, which looks like *Figure 32.*

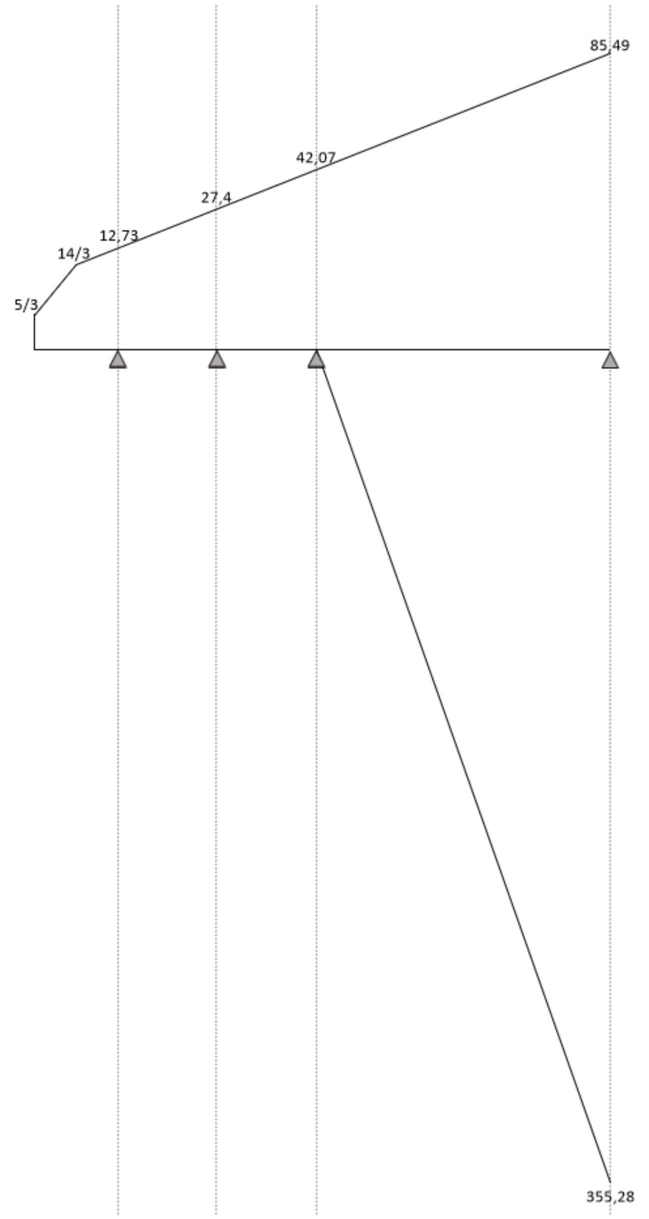


Figure 32: Current system

Fixed End Moments

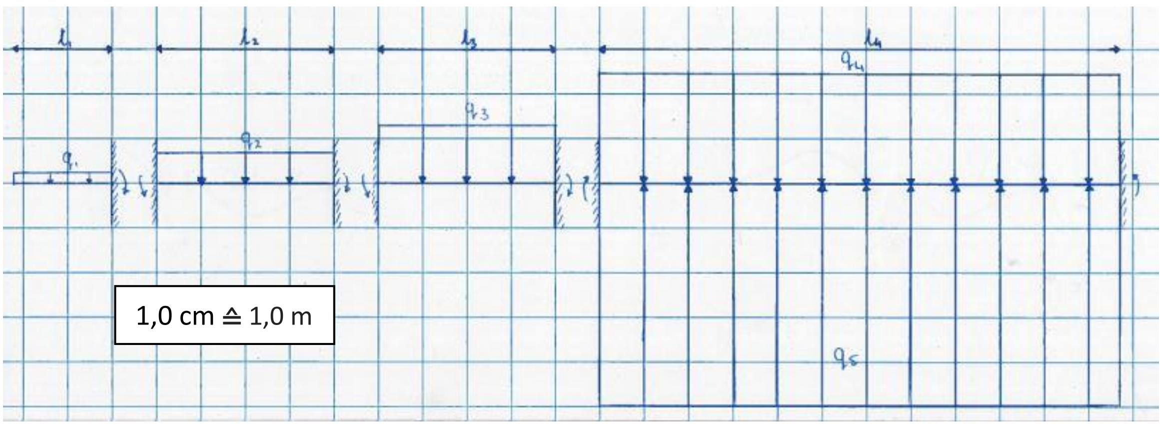


Figure 33: Fixed End Moments of system

$$q_6 = q_5 - q_4$$

$$q_6 = 2103{,}2741 - 425{,}3328$$

$$q_6 = 1677{,}9413\ kN/m$$

With this new q-load the system will change. This can be seen in *Figure 34:*

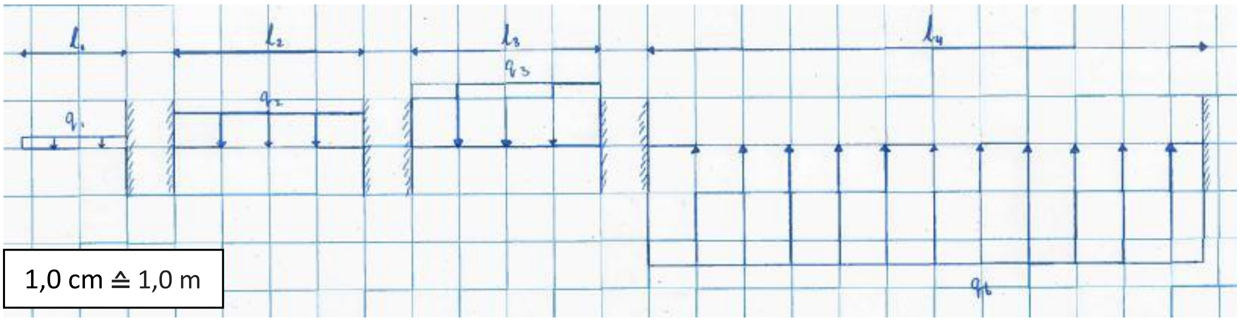


Figure 34: Fixed End Moments with new q-load

$$M_{AB} = \frac{1}{2} * q_1 * l_1^2$$

$$M_{AB} = \frac{1}{2} * 19{,}206 * 2{,}2^2$$

$$M_{AB} = 46{,}479\ kNm$$

$$M_{BC} = -\frac{1}{12} * q_2 * l_2^2$$

$$M_{BC} = -\frac{1}{12} * 80{,}267 * 4^2$$

$$M_{BC} = -107{,}021\ kNm$$

$$M_{CB} = \frac{1}{12} * q_2 * l_2^2$$

$$M_{CB} = \frac{1}{12} * 80{,}267 * 4^2$$

$$M_{CB} = 107{,}021\ kNm$$

$$M_{CD} = -\frac{1}{12} * q_3 * l_3^2$$

$$M_{CD} = -\frac{1}{12} * 138{,}933 * 4^2$$

$$M_{CD} = -185{,}244\ kNm$$

$$M_{DC} = \frac{1}{12} * q_3 * l_3^2$$

$M_{DC} = \frac{1}{12} * 138{,}933 * 4^2$

$M_{DC} = 185{,}244\ kNm$

$$M_{DE} = -\frac{1}{12} * q_4 * l_4^2$$

$M_{DE} = -\frac{1}{12} * 1677{,}941 * 11{,}84^2$

$M_{DE} = -19601{,}934\ kNm$

$$M_{ED} = \frac{1}{12} * q_4 * l_4^2$$

$M_{ED} = \frac{1}{12} * 1677{,}941 * 11{,}84^2$

$M_{ED} = 19601{,}934\ kNm$

Calculating C, µ and COF

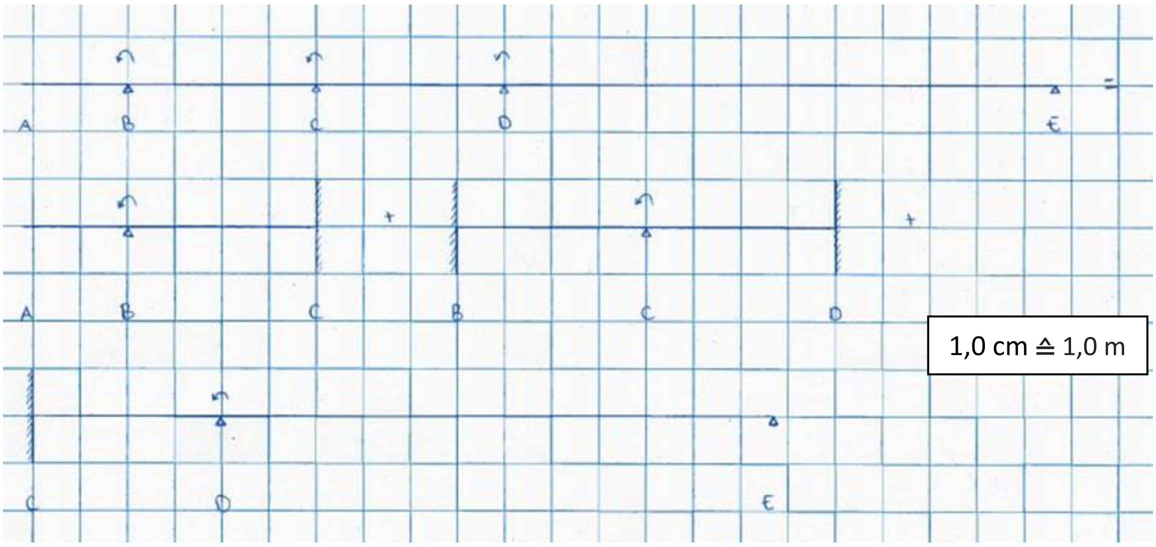


Figure 35: Splitted system in different nodes

Node B

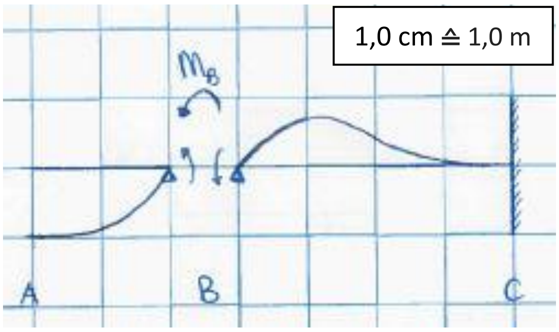


Figure 36: Node B

$$C_{BA} = \frac{M}{\varphi} = 0\ (moment\ cannot\ be\ distributed)$$

$$C_{BC} = \frac{M}{\varphi} = \frac{4EI}{l_2} = \frac{4EI}{4} = EI$$

$$\sum C = C_{BA} + C_{BC} = 0 + EI = EI$$

Distribution factor

$$\mu_{BA} = \frac{C_{BA}}{\sum C} = \frac{0}{EI} = 0$$

$$\mu_{BC} = \frac{C_{BC}}{\sum C} = \frac{EI}{EI} = 1$$

Carry-over-factor

$$M_{CB} = \frac{1}{2} M_{BC}$$

Node C

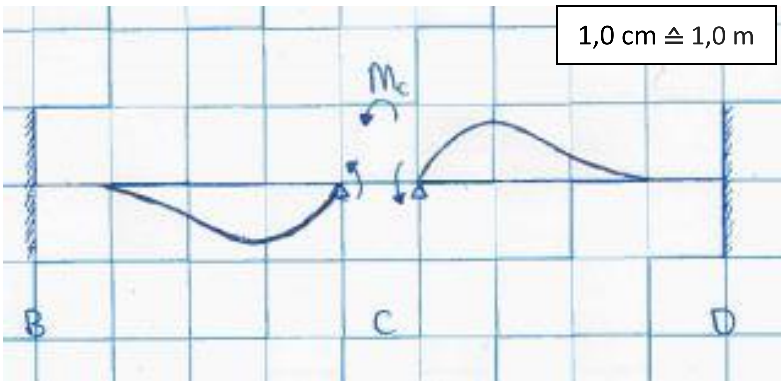


Figure 37: Node C

$$C_{CB} = \frac{M}{\varphi} = \frac{4EI}{l_2} = \frac{4EI}{4} = EI$$

$$C_{CD} = \frac{M}{\varphi} = \frac{4EI}{l_3} = \frac{4EI}{4} = EI$$

$$\sum C = C_{CB} + C_{CD} = EI + EI = 2EI$$

Distribution factor

$$\mu_{CB} = \frac{C_{CB}}{\sum C} = \frac{EI}{2EI} = \frac{1}{2}$$

$$\mu_{CD} = \frac{C_{CD}}{\sum C} = \frac{EI}{2EI} = \frac{1}{2}$$

Carry-over-factor

$$M_{BC} = \frac{1}{2} M_{CB}$$

$$M_{DC} = \frac{1}{2} M_{CD}$$

Node D

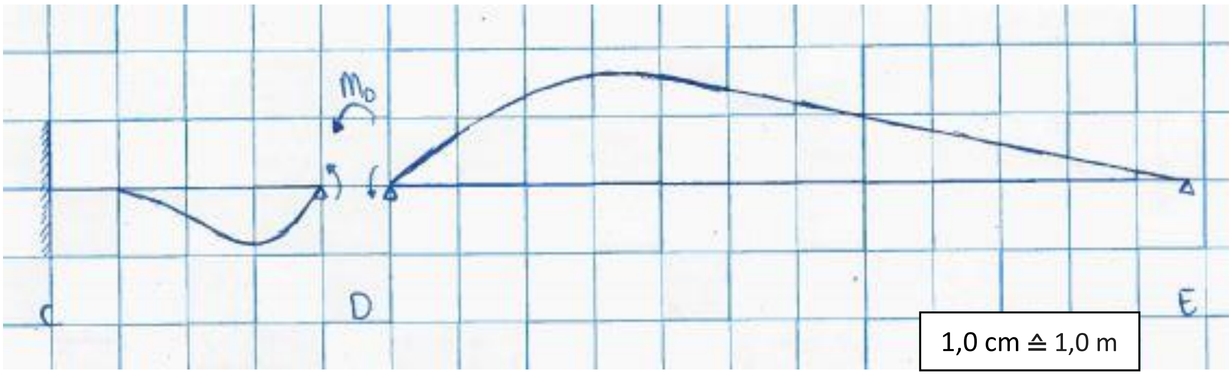


Figure 38: Node D

$$C_{DC} = \frac{M}{\varphi} = \frac{4EI}{l_3} = \frac{4EI}{4} = EI$$

$$C_{DE} = \frac{M}{\varphi} = \frac{3EI}{l_4} = \frac{3EI}{11,84} = 0,2533 \dots EI$$

$$\sum C = C_{DC} + C_{DE} = EI + 0,2533 \dots EI = 1,2533 \dots EI$$

Distribution factor

$$\mu_{DC} = \frac{C_{DC}}{\sum C} = \frac{EI}{1,2533 \dots EI} = 0,798$$

$$\mu_{DE} = \frac{C_{DE}}{\sum C} = \frac{0,2533 \dots EI}{1,2533 \dots EI} = 0,202$$

Carry-over-factor

$$M_{CD} = \frac{1}{2} M_{DC}$$

Table to calculate the distributed moments

Table 11: Calculation distributed moments

	B		C		D		E
	BA	BC	CB	CD	DC	DE	ED
DF	0,0	1,0	0,5	0,5	0,798	0,202	
COF		0,5 ->	<- 0,5	0,5 ->	<- 0,5		
FEM	-46,5	107,0	-107,0	182,5	-182,5	-19601,9	19601,9
				7892,4	15784,9	3999,5	
		-1992,0	-3984,0	-3984,0	-1992,0		
	0,0	1992,0	996,0	794,6	1589,3	402,7	
		-447,7	-895,3	-895,3	-447,7		
	0,0	447,7	223,8	178,6	357,2	90,5	
		-100,6	-201,2	-201,2	-100,6		
	0,0	100,6	50,3	40,1	80,3	20,3	
		-22,6	-45,2	-45,2	-22,6		
	0,0	22,6	11,3	9,0	18,0	4,6	
		-5,1	-10,2	-10,2	-5,1		
	0,0	5,1	2,5	2,0	4,1	1,0	
		-1,1	-2,3	-2,3	-1,1		
	0,0	1,1	0,6	0,5	0,9	0,2	
		-0,3	-0,5	-0,5	-0,3		
	0,0	0,3	0,1	0,1	0,2	-0,1	
		-0,1	-0,1	-0,1	-0,1		
	0,0	0,1	0,1	0,0	0,0	0,0	
		x	0,0	0,0	x		
Total	-46,5	107,0	-3961,1	3961,1	15082,9	-15083,0	19601,9

In conclusion, in point A there will not be a moment because there is no hinge and thus the moment cannot be distributed. In point B the moment will be $M_{BA} + M_{BC} = -46{,}5 + 107 = 60{,}5\ kNm.$ Furthermore, in point C and D the moment is zero because M_{CB} & M_{CD} and M_{DC} & M_{DE} are equal to each other. And at last the moment in E will be 19601,9 kNm.

Those moments can be recalculated to forces. The smallest width of the parking garage is around 66 meters wide. When the width is at its lowest, the force will be at its highest.

To calculate the force there will be made use of $M = F * a$, in which the moment, M, depends on the beam and the arm, a, is 66 meters.

Point B

$$F_B = \frac{M_B}{a}$$

When filling in the formula, this will result in:

$$F_B = \frac{60{,}5}{66} = 0{,}917\ kN$$

Point E

$$F_E = \frac{M_E}{a}$$

When filling in the formula, this will result in:

$$F_E = \frac{19601{,}9}{66} = 296{,}998\ kN$$

These values are not really realistic so this will be addressed in the discussion.

Points of interest

The point E which is used in the calculations of the beams is not correct. Firstly, because there is in reality not a hinge on the sheet pile. This assumption is made because the sheet pile will not move but if there is an calculation made without the hinge, the calculation is incorrect.

Despite the assumption of the hinge the calculation is still not correct. This is caused due to the fact that the ‘exact’ location of the hinge is not calculated. The location will never be completely certain but with the calculation there can be an estimation made. This calculation should be done by making use of Q-, V-, M-diagrams.

G: Circular Economy & Sustainability

G.1 Background information

In April of 1968 a group of thirty individuals reunited to analyse the present and the future of the human being. This led the concept of circularity being a topic of discussion. In 1970 at the Massachusetts Institute of Technology an international team discussed the implications and effects of worldwide growth. They examined specifically five basic factors which are: agricultural production, natural resources, industrial production, pollution and population (Meadows, 1975). Eventually, this led to the publication of the book “Limits of Growth”. In the book is discussed that man can establish limits in the consumption of natural resources in order to achieve an equilibrium between the population growth and the production of goods.

Circular economy has gained acceptance through the years. Climate change and the possible run out of raw materials drives different companies to adopt zero-waste circular cycles which are more sustainable. It is an environmentally responsible option which emphasize design of objects, parts of objects or materials of objects which can be reused. Different solutions for the implementation of circular economy should be economically feasible. Furthermore, communication is essential between supply chain partners in order to succeed in the application of Circular and Sustainable principles. (MVO Nederland & Duurzaam Bedrijfsleven, 2016)

Netherlands is an advanced country in terms of recycling and reuse of the construction and demolition waste (Rijkswaterstaat, 2015). Enschede wants to be more environmentally friendly by implementing Circular and Sustainable (C&S) principles in the construction of a new parking garage. More specifically, it was decided that two elements which are: pre-cast concrete and lighting system are going to comply with C&S principles.

G.2 Elements

Circularity Economy has different elements which are suitable to understand how the business focus is going to change, the new organization of supply chain and the interaction between customers and the products. Furthermore, these elements allow to succeed in the application of a circular lifecycle (MVO Nederland & Duurzaam Bedrijfsleven, 2016). The mentioned elements are:

- **Strategy:** adopting Circular Economy principles means a change in focus (strategy) on maximising sales to loops of different products and services to increase incomes.
- **Procurement and collaboration:** circular procurement contemplates different factors such as durability and recyclability of the products. This requires collaboration from the suppliers in order to meet the requirements of the Circularity.
- **Design and Production:** the focus changes from products with one life cycle to durable and recyclable products. Thus, the design is made to minimize the environmental impacts and to be used for many life cycles.
- **Waste management:** the decrement of raw materials and resources along the time makes important to consider to recover valuable resources from waste. Therefore, it is important implement reverse logistics to recover waste.

G.3 Principles

Different principles will be taken into account in the designing process of the parking garage. Specially, in the implementation of pre-cast concrete and lighting system. According to the Ministry Infrastructure and Environment (Rijkswaterstaat, 2015) the principles in C&S are:

- **Product re-use:** the same product is reused for the same function
- **Repair:** amend a product in order to use it for an identical function.
- **Remanufacture:** when a part of the product is used for the same function.
- **Recycle:** in this process the materials are recovered to be reused in a new lifecycle. There are two qualifications for the process of recycling which are: high-quality reuse (or 'upcycling') which means that the components can be used for the same type of function or product. And low-quality reuse (or 'downcycling') meaning that the reusing options were limited and it was possible to reuse it for a simpler product (Rijkswaterstaat, 2015).

With the implementation of these principles is possible to design the different elements to be reused, repaired, remanufactured or recycled at the end of their lifecycles. In other words, give a purpose for the different construction elements at the final stage of their lifecycle.

G.4 Concrete

Motivation for choice

Concrete buildings have adopted a linear lifecycle model which makes it not reusable. They are designed without adaptability and potential for change. On the other hand, concrete technologies had developed self-cleaning concrete, self-healing concrete and ultra-strength concrete. Which makes it possible to implement new applications and practices.

Important reasons motivated the selection of concrete as a suitable material to implement Circular and Sustainable principles. Many experts have considered the current linear lifecycle which ends in demolition as a design error (Durmisevic & Yeang, 2009). Morrison Hershfield Engineering showed that 1.23 GJ of energy can be saved by reusing concrete (Huuhka, Kaasalainen, Hakanen, & Lahdensivu, 2015). Furthermore, concrete provides different functions is all physical levels of the building such as load bearing, enclosing, protection, and appearance. When the constructions are demolished 25 % of the energy of infrastructure and operation is lost. The new model "Cradle to Cradle" will make it possible to conserve energy to manufacture products, reduce CO_2 emissions, waste and dust pollutants (Crowther, Design for disassembly to extend life and increase sustainability, 1999).

Design for disassembly (DFD) is a key concept to be taken into account in the design of the parking garage. The mentioned concept applied makes it possible to avoid the demolition of concrete buildings. With the help of concrete technologies which can be applied in the construction of removable elements. For instance, the use of ultra-strength concrete to produce thin elements which can be handled easily. *Figure 39* shows the change in lifecycle of concrete by the application of DFD concept (Salama, 2017). As it is shown the linear lifecycle ends in demolition, while in the cyclic model the objects can be reused and the whole process starts again.

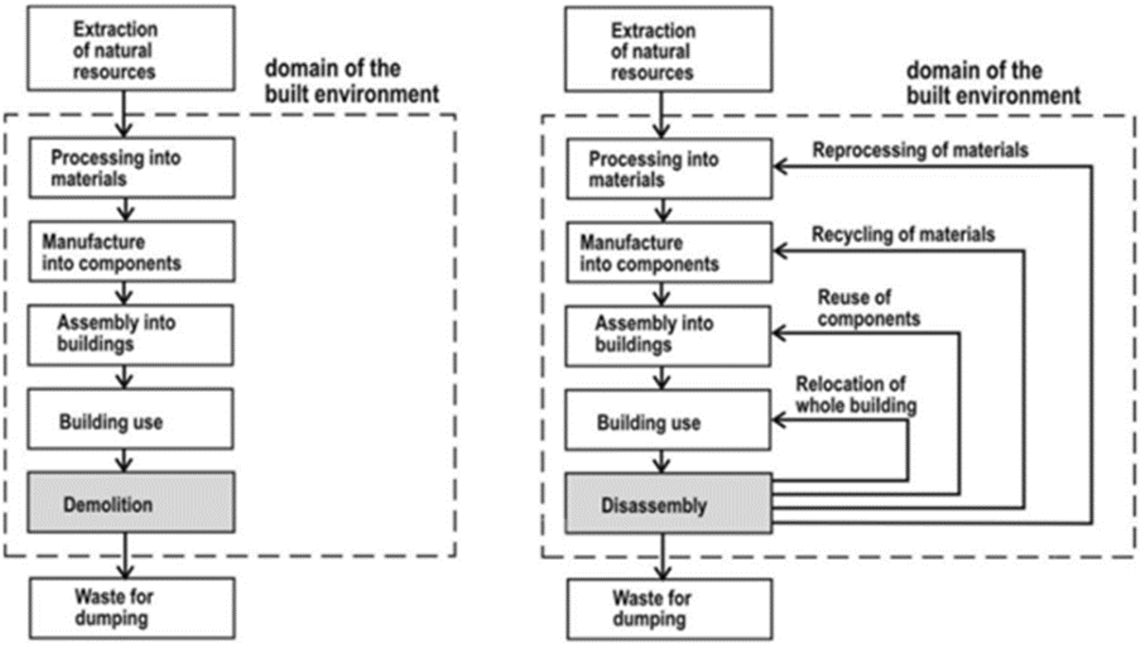


Figure 39: Change of linear lifecycle to a cyclic model through disassembly (Crowther, 2015)

Life cycle analysis

The parking garage will be implemented with good quality recyclable materials which can produce less environmental impact. Even though the reuse of parts of concrete buildings can be difficult and costly there are some successful projects which can serve as a guide to reuse precast concrete elements. As in the case of a house in Berlin which was constructed with the ‘‘Plattenbau” construction technique, which resulted in a 30% reduction cost (Stacey, 2011). Furthermore, recent studies indicated that there is a reduction in the total building cost of 26 % by reusing construction elements (Glias, 2013).

With the objective of satisfying the requirements of the interested parties it is important to consider carefully how to close the supply chain circle and how it will be organized in order to succeed. The stakeholders want objects that can be easily removed and to spend less money. Procurement and collaboration are also important between supplies chain players which of course want to get business out of these new models.

It was decided to work with Consolis Spanbeton which is a company in Netherlands of the Consolis Group. In Europe this group is the leading provider of precast concrete. Furthermore, provides suitable and sustainable precast concrete structures (Consolis, 2018). Spanbeton offers experience in the field of precast infrastructures. Spanbeton is located in Koudekerk, even though is a long distance from the site of construction. The experience of the company in precast concrete and the implementation of circular principles in their projects motivated the group to work with this prestigious company.

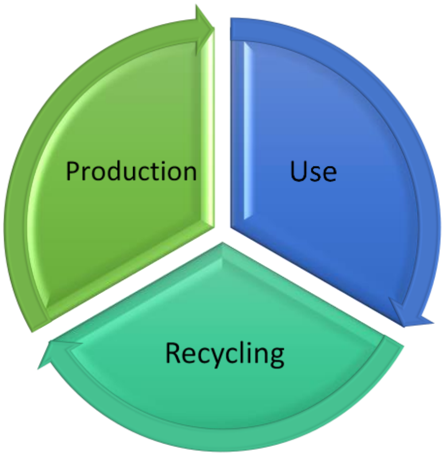


Figure 40: The lifecycle of concrete with C&S principles

As it is shown in *Figure 40* the first phase starts with the production engineers of Spanbeton work together to find the most feasible solutions for the parking garage. With the use of the advanced software, drawing programs and 3-D modelling. They also provide support in the construction phase with their own specialized installation team. They work with the transport and casting work. Finally, at the end of the lifecycle it is necessary to find a purpose for the precast concrete as it was described before there are some successful projects in which precast concrete has served for other purposes (Spanbeton, sd). Then, it is feasible to recycle (low-quality reuse principle) the different parts to construct houses in the future as in the case of the house in Mehrow, Berlin as is shown if *Figure 41.*

Figure 41: The house constructed with recycled concrete slabs (Glias, 2013)

The same technique "Plattenbau" will be implemented at the end of the use of the different concrete slabs. Because the technical standards are good which means that they can be reused. The slabs get stronger as they dry out with the pass of the time. At the end the panels should be certified in order to be used in other constructions. It results on a cheaper process and it does not take a lot of time to reuse the pre-cast concrete in new constructions. In order to keep the parts together only bolts and steel ties are necessary, because the slabs are strong and no extra structure is needed (The Guardian, 2005).

G.5 Lighting

Motivation for choice

The development of the concept “Light as a Service” has changed the way in which the companies work with their suppliers. These change requires the management of logistics and the change in relations with the clients. Companies that have adopted these concepts owns the equipment, which allows them to recycle the different components of the lighting systems.

According to Van der Vloed circular light is from 5 to 20% cheaper. With these concepts the user pays for the use and not for the purchase of the fixtures (MVO Nederland & Duurzaam Bedrijfsleven, 2016). It is important then that the products can be put again in circulation by recycling or by recovering the different parts of the lighting. Another important benefit is the reduction in carbon emissions compared to other lighting sources.

Different reasons motivated the selection of LED lighting as a suitable object for the parking garage. LED lighting is going to replace conventional light sources (incandescent light bulbs and compact fluorescent lamps CFL). Even though the initial cost of convectional light sources is less than the LED’s when the operational and maintenance cost are included there is a significant difference between costs making LED a cheaper option. Due to the fact that LED’s have a longer lifetime the different fixtures and illumination itself represent less cost in terms of replacement including the expenditures in labour. This type of illumination consumes less energy than the conventional light sources and is more efficient with an excellent quality in terms of illumination (Signify Holding, 2018). In order to understand the benefits that it is possible to achieve a comparison is made between LED, CFL and incandescent lighting (Alt, 2019).

Table 12: Comparison between LED, CFL and incandescent light bulbs (Alt, 2019)

	LED	CFL	Incandescent
Watts used	10.5 W	15 W	60 W
Watt equivalence	60 W	60 W	60 W
Average cost per bulb	€ 4.50	€ 2.70	€ 0.90
Lifespan in hours	15.000	8.000	1.100
Bulbs needed for 15,000 hours	1	2	14

As the *Table 42* shows LED lighting consumes less energy than other conventional illumination sources. This makes it an environmentally friendly option. It is worth to emphasize that the lifespan of LED lighting is 15,000 hours making it a cheaper option.

Life cycle analysis

In order to implement circular illumination systems in the parking garage it was decided to work with Philips. The decision was made by carefully considering the different benefits of working with this company. Due to the fact that there are already successful projects in which C&S principles were implemented as in the case of Schiphol Airport in Amsterdam. Furthermore, Philips works with the concept of “Light as a Service”. Which means that the “property” will be replaced by the “use”. This sustainable program led Philips to important benefits for the world. For instance, the reduction of its carbon footprint by 20 % to 325 kilotons CO2 in 2017. This was combined with the fact that there was an increase in the usage of renewable sources for electricity from 67% to 80%. Which means that as a company they implement circular and sustainable principles in their work. Which results in a reduction of waste materials of approximately 26 % which is beneficial for the environment (Signify Holding, 2018). It is worth to point out that their products last longer and are easy to upgrade and maintain.

Figure 42: The lifecycle of Philips Lighting systems (Philips)

Philips has incorporated a circular model which allows them to develop green products as in the case of the illumination systems. *Figure 43* shows the how the supply chain according to Philips is organized. The creation of LED lighting is the first step in the supply chain. Philips distributes their products to the different branch offices in all the country. In order to receive the different elements and components of lighting is necessary to search for the nearest agency. The main agencies are located in Amsterdam and Eindhoven. Therefore, it is feasible to work with the agency of Eindhoven. Philips will provide assessments in order to identify possible savings. Thus, experts will install the different products in the parking garage. In the second step which is the use they will take care of the rest by disposing the old luminaires. Furthermore, they are going to deliver, install, and commission the new lighting system. It is important to take into account the maintenance and optimization of the system. Finally, when the systems had fulfilled its purpose during a certain time of life. Philips is the uncharged of recover the different components of the products and give them a new purpose.

The parking garage consists of two floors in total 9660 m^2. The lighting systems are required for the parking spots and storage rooms. By the implementation of LED lighting there is a reduction up to 80% of energy consumption (Philips Lighting, sd). It is worth to mention that the reduction in cost of the lighting costs of the parking garage was calculated in the finance part. As it was demonstrated in *table 12* it is a cheaper option and is not necessary to worry about the maintenance or repairs. Also, illumination system helps to reduce the C02 emissions due to the reduction in consumption of the kW/hr. There is no risk in buying light as a service like other utilities for instance gas and water. With all these benefits it is possible to take advantage of the cost savings and energy savings (Philips Lighting, sd).

H: Finance – Cash flow overview

PROJECT CASH FLOWS		
Discount rate (r)	=	4.5%
Amount of parking spaces	=	245

Occupancy rates	
Car occupancy rate general public: Hour rate	0.45
Car occupancy rate subscription: Residents	0.5
Car occupancy rate subscription: Workers	0.05

Time (years)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cash inflow																
Total occupancy rate parking garage		0.34	0.35	0.36	0.37	0.38	0.39	0.4	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Total occupancy parking garage		83	86	88	91	93	96	98	100	103	103	103	103	103	103	103
General public																
Car occupancy general public		37	39	40	41	42	43	44	45	46	46	46	46	46	46	46
Used hours per year		328368.6	338026.5	347684.4	357342.3	367000.2	376658.1	386316	395973.9	405631.8	405631.8	405631.8	405631.8	405631.8	405631.8	405631.8
Rate per hour		€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20	€ 2.20
Cash inflow hour rate		€ 722,410.92	€ 743,658.30	€ 764,905.68	€ 786,153.06	€ 807,400.44	€ 828,647.82	€ 849,895.20	€ 871,142.58	€ 892,389.96	€ 892,389.96	€ 892,389.96	€ 892,389.96	€ 892,389.96	€ 892,389.96	€ 892,389.96
Residents: Subscription																
Car occupancy residents subscription per year		42	43	44	45	47	48	49	50	51	51	51	51	51	51	51
Subscription rate per year		€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00	€ 565.00
Cash inflow subscription residents		€ 23,532.25	€ 24,224.38	€ 24,916.50	€ 25,608.63	€ 26,300.75	€ 26,992.88	€ 27,685.00	€ 28,377.13	€ 29,069.25	€ 29,069.25	€ 29,069.25	€ 29,069.25	€ 29,069.25	€ 29,069.25	€ 29,069.25
Workers: Subscription																
Car occupancy workers subscription per year		4	4	4	5	5	5	5	5	5	5	5	5	5	5	5
Subscription rate per year		€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00	€ 656.00
Cash inflow subscription workers		€ 2,732.24	€ 2,812.60	€ 2,892.96	€ 2,973.32	€ 3,053.68	€ 3,134.04	€ 3,214.40	€ 3,294.76	€ 3,375.12	€ 3,375.12	€ 3,375.12	€ 3,375.12	€ 3,375.12	€ 3,375.12	€ 3,375.12
Advertisement per year (constant value)		€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00	€ 8,000.00
Cash inflow per year		**€ 756,675.41**	**€ 778,695.28**	**€ 800,715.14**	**€ 822,735.01**	**€ 844,754.87**	**€ 866,774.74**	**€ 888,794.60**	**€ 910,814.47**	**€ 932,834.33**	**€ 932,834.33**	**€ 932,834.33**	**€ 932,834.33**	**€ 932,834.33**	**€ 932,834.33**	**€ 932,834.33**
Cash outflow																
Building costs																
Building works/construction	€ 5,116,710.55															
Installations	€ 946,644.60															
Remaining building costs	€ 1,220,347.80															
Cash outflow building	€ 7,283,702.95															
Maintenance costs		€ 56,350.00	€ 56,350.00	€ 56,350.00	€ 56,350.00	€ 56,350.00	€ 56,350.00	€ 56,350.00	€ 56,350.00	€ 56,350.00	€ 129,850.00	€ 56,350.00	€ 56,350.00	€ 56,350.00	€ 56,350.00	€ 56,350.00
Employee costs		€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88	€ 23,552.88
Lighting costs		€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00	€ 112,392.00
Water costs		€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60	€ 232.60
Energy costs (without lighting)		€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25	€ 26,031.25
Cash outflow per year	**€ 7,283,702.95**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 292,058.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**	**€ 218,558.73**
Netto cashflow	**€ -7,283,702.95**	**€ 538,116.68**	**€ 560,136.55**	**€ 582,156.41**	**€ 604,176.28**	**€ 626,196.14**	**€ 648,216.01**	**€ 670,235.87**	**€ 692,255.74**	**€ 714,275.60**	**€ 640,775.60**	**€ 714,275.60**	**€ 714,275.60**	**€ 714,275.60**	**€ 714,275.60**	**€ 714,275.60**
Discount factor	1.00	0.96	0.92	0.88	0.84	0.80	0.77	0.73	0.70	0.67	0.64	0.62	0.59	0.56	0.54	0.52
Present value	€ -7,283,702.95	€ 514,944.19	€ 512,933.81	€ 510,141.69	€ 506,638.87	€ 502,491.75	€ 497,762.31	€ 492,508.39	€ 486,783.94	€ 480,639.21	€ 412,613.15	€ 440,135.72	€ 421,182.51	€ 403,045.46	€ 385,689.44	€ 369,080.80