Managing the development of a two-story storage park

As commisioned by:

salland storage

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Preface

Before I started my academic journey at the University of Twente, I was faced with the difficult choice between Industrial Design Engineering and Mechanical Engineering. While I loved the functional and practical side of both, IDE drew me in more due to the involvement in the entire process – from a problem all the way to a functional solution. During my first few years, I struggled with encapsulating aesthetically pleasing elements in my design, yet I thrived in solving functional issues of the products we were designing. This was also what I searched for in a thesis: a difficult problem that would require analysing a lot of different aspects in order to come to a proper solution.

Salland Storage were the ones to provided me with the answer to that search, in the form of this thesis: "Managing the development of a two-story storage park". After talking to them for a while at their booth during a career fair, they received my email the very same day.

Salland Storage proved a very fine client, who gave me the freedom to think big and were always open to testing different ideas. I would like to thank them for the opportunity that they gave me, in particular Danny, who was also the external supervisor of this thesis.

I would also like to thank Ilanit, who was always interested in listening to me rambling on – and provided excellent feedback and supervision during the course of this thesis.

Lastly, I would also like to thank my friends, my family, and my girlfriend Florentien who were always open to let me bounce ideas of them – whether they enjoyed it or not. Not only were they always supportive, but more than once inspiration was drawn from the ideas that they gave me.

I hope you enjoy!

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Summary

The research question that is answered in this master's thesis is "How can the Z-box successfully be rented out by Salland Storage while stacked two high?". In other terms, the client (Salland Storage) wants to rent out a two-story storage park that consists of self storage containers called the Z-box.

Due to the time window in which a master's thesis will have to be performed, it is not realistic to aim for a fully up-and-running two-story storage park. However, answering the research question in a satisfactory manner will allow Salland Storage to plan out a road map, while performing and validating tests in a more effective way.

Answering this research question will be done in a series of chapters that will all build from each other. In the initial exploration, the different aspects of this two-story storage park will have to be defined. This builds an understanding to not only the stakeholders of this project, but also the object at the core of this park: the Z-box. On top of that, the current situation at Salland Storage will have to be analysed to study their progress with regards to the development of a two-story storage park. This consists of an analysis of the practical & theoretical work that has already been performed prior to this thesis.

After this exploration, a solid starting point for the remainder of the thesis is defined. Building on this, literature researched is performed to define the legislative requirements that will need to be kept in consideration for this two-story storage park. Analysing the profitability at such an early stage is deemed ineffective, yet some research will be performed to determine the user demands and possible layout variations for the two-story storage park. This section will also formulate the two main requirements that will drive the remainder of the thesis.

This research continues by taking a look at the more subjective aspects. The customers of the park will not be aware of development involved in making the park safe, but they still have to feel safe when using the two-story storage park. Literature research is therefore performed that aims to capture the different aspects that make up this feeling, and a tool is developed that can be used in a later stage of development to adapt certain sections of the park to increase the perceived safety and appearance of them. Following this research, a thorough set of simulations is performed to determine the strength of several critical areas in the park. Not only is this chapter utilized to validate the layouts created earlier, but the results of these simulations will determine the path of development moving forward.

The development chapter following the simulation starts by trying to solve the issues that have come up during the simulations. Also, redundancy is introduced in the in the form of brackets that allow the Z-boxes to be joined. While the brackets will have to be custom made to suit the needs in the park, peripherals like bridges and stairs can be bought off-the-shelf. The tool developed during the research can be used to increase the perceived safety and appearance while keeping the main functionality intact. While this tool is based on literature research, there are still some subjective aspects to it. Therefore, this chapter will also perform an evaluation on the developed tool.

All of the work stated will combine in the form of a case study. The goal of this case study is to not only find certain overlooked parts in the design, but also serves as a cost analysis. Performing this cost analysis will allow a validation on the profitability of a two-story storage park. The thesis will close of with a set of instructions for Salland Storage, consisting of the construction method of the park, followed by a series of suggested tests that might introduce issues when performing the construction.

1 Introduction

1.1 Company

For as long as humans have struggled with maximizing the usable space in a limited footprint, one principle has been utilized over and over again: building upwards. This same principle was the drive behind this master's thesis as commissioned by a company called Salland Storage, located in Deventer, the Netherlands. Salland Storage is a company that facilitates storage solutions for both consumers and businesses. This takes shape in the form of parks filled with storage boxes, called Z-boxes. These parks are located throughout the Netherlands. The number of Z-boxes, and thus their profit, is limited by the amount of usable footprint for these parks. Salland Storage wants to apply the same principle of 'building upwards' to the Z-boxes. Stacking them in a usable manner in order to effectively double their usable footprint and thus their revenue. This desire to stack their Z-boxes is not a new one, and several tests have already been performed at their home base in Deventer. However, up until the start of this thesis the tests have had no clear definition of success behind them. This not only hurts the effectiveness of this testing phase, but also lacks a clear path for subsequent ones. Their end-goal is to rent out a two-story storage park, but the means of how to get there are still relatively unknown. Effectively, this is the reasoning behind the commissioning of this thesis.

1.2 Research Question

In order to guide the work performed throughout this thesis, a research question will have to be defined. First of all, an important part of the research question will have to focus on how to actually rent out the Z-box while it is being stacked two high. While at first glance this seems rather basic, the opposite is true. Salland Storage cannot just put another Z-box on top of their existing storage boxes and call it a day. Sufficient research will have to be performed on the legal aspects (i.e., the construction or building laws), the safety aspects, and the profitability aspects. In collaboration with Salland Storage, the following research question was proposed:

"How can the Z-box successfully be rented out by Salland Storage while stacked two high?"

One of the most important words in this research question is "successfully". In order to declare something as a success, goals need to be set that make up this definition. In the case of renting out the Z-box, there are three main pillars that define its success: Legality, Profitability, and Safety. All of these work in conjunction with each other and will all have to be kept in mind during the development of this two-story storage park.

1.3 Plan of Approach

The earlier stated research question will be answered by following the plan of approach that can be seen in Figure 1. Each of the different chapters will bring conclusions forward that can be taken as a starting point for the following chapter. At the start of each chapter in this thesis, a more detailed view of this plan of approach will be shown.

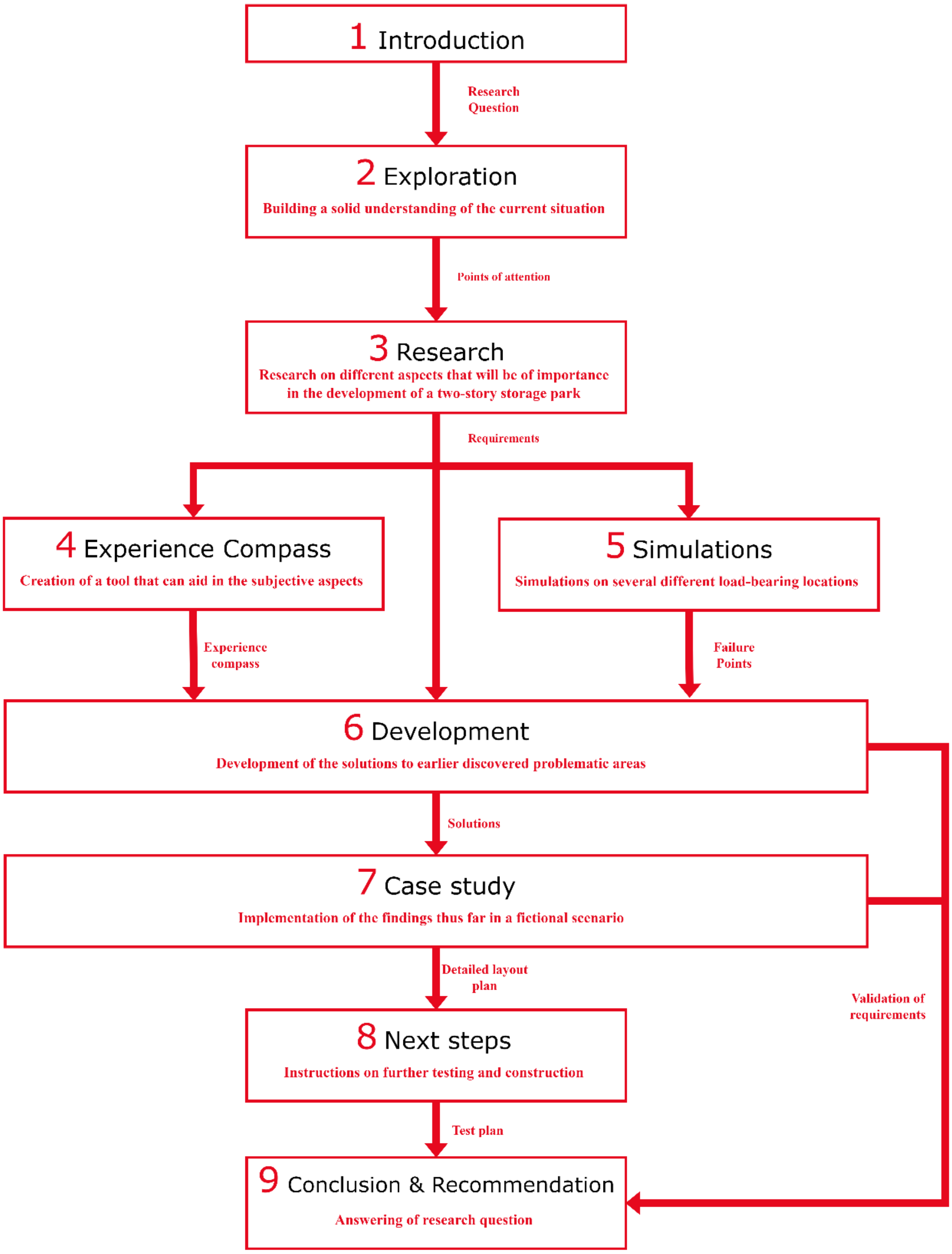


Figure 1 Plan of approach

2 Exploration

To start the process of answering the earlier formulated research question, the current state of the progress will have to be determined. This chapter will therefore have a goal of developing a proper understanding of the current situation and serves as a way to determine the current progress that Salland Storage has made on their way to a two-story storage park. The stakeholders, Z-boxes, and prior work will be explored in this section. This section will conclude with some points of attention, that can be brought forward to chapter 3. A visual representation of chapter 2 can be seen in Figure 2.

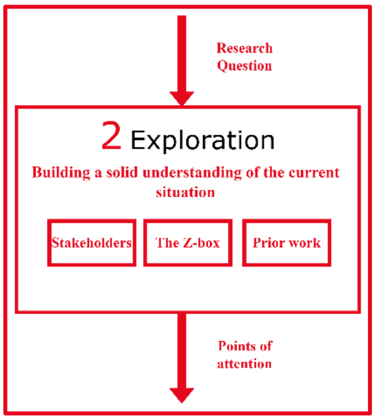


Figure 2 Plan of approach - Exploration

2.1 Stakeholders

This stakeholder exploration is used to identify and understand the key individuals and groups, whose interests and concerns will have to be taken into account during the course of this thesis.

2.1.1 Salland Storage

The main client of this thesis is Salland Storage. [1] The company itself is located in Deventer, a city in the eastern part of the Netherlands. Founded in 2006, they rent out storage solutions [2], both for professional as well as consumer use. The storage solutions include car & bike storage, a personal container called the Stowbox [3], and self storage boxes [4]. These self storage boxes, also called the Z-boxes, are the main topic of this thesis. Salland Storage does not produce these Z-boxes themselves but instead buys them from a company called Universal Storage Containers [5], who will be discussed at a later section.

Salland Storage deploys these Z-boxes at several locations throughout the Netherlands in the form of a centralized storage park, as can be seen on Figure 3. These parks themselves often consist of several rows of Z-boxes. The rows are spaced in a way that allows users to drive a car through them, allowing for easier loading and unloading of the boxes.

Figure 3. Storage park located in Deventer, the Netherlands

The parks can be found in the following locations in the Netherlands [1]:

- Deventer
- Almelo
- Duiven
- Zutphen

The price for renting a storage box from Salland Storage depends on the size. At the time of writing (March 2023) the following prices can be found on the website [4]:

	Surface Area [m^2]	Volume[m^3]	Approximate number of boxes	Price per 4 weeks	Price per m^2
Option 1	1.75	4	50	€25	€14.29
Option 2	3.5	8	100	€39	€11.14
Option 3	7	16	200	€79	€11.29
Option 4	14	32	400	€139	€9.90

Table 1: Different storage prices at Salland Storage

The 'approximate number of boxes' refers to their estimation on the number of moving boxes that can comfortably be stored. Also, as 4 weeks is the defined period that the client uses it is also used in this thesis as opposed to a month. Lastly, the client′s wishes are quite straightforward. As a business first and foremost, profit is of importance.

2.1.2 Universal Storage Containers

As mentioned earlier, the self storage boxes are also called "Z-boxes". The Z-box is a product of a company called Universal Storage Containers (USC) [5]. Something that is worth clarifying is that USC is the name of both the parent company located in the United States, and the name of the European section of the company located in Deventer. While they share the same name, the range of products differs. The European section of the company only sells Z-boxes, with their main focus being storage facilitators such as Salland Storage. This means that the findings in this thesis will also be of importance to USC itself. The primary reason they are not considered a main client is because of the scope of the thesis. USC sells storage boxes to other storage facilitators throughout Europe. Considering the building legislation in the Netherlands regarding the stacking of Z-boxes is one thing, analysing building codes that are used in different countries throughout Europe broadens the scope too much. This is also why the European part of the company is only considered as a stakeholder. It is worth noting that the European part of the company is managed by the same two brothers who also manage Salland Storage.
In short, USC (Europe) sells their Z-boxes to companies that rent out storage parks. One of these companies being Salland Storage.

Figure 4: Logo of Universal Storage Containers

Assembly Crew

The assembly crew is employed by USC and responsible for setting up the storage parks. This assembly crew is made up out of two employees who cost around €450 a day. A set of instructions for stacking the Z-boxes does need to be defined, and this needs to be communicated in a clear and concise manner. Also, it is important to keep the assembly crew in mind when designing a solution. If a substantial amount of work goes into peripheral matters surrounding the stacking of the structure, it would not only be disadvantageous for them but also will cost USC and in effect Salland Storage extra in the parks' initial construction cost.

2.1.3 Customers

The customers are arguably the most important stakeholders in this project. While the client of the thesis is Salland Storage, the customers will be the ones that ultimately interact with the proposed solution. That means that the solution needs to be suited to them as well. In order to build an understanding of the customers, a look can be taken at the current customers of the storage park in Deventer.

According to the client, the park in Deventer is fully rented out, and multiple customers have requested extra storage space. This shows that there is sufficient demand by the customers, and they would benefit from a two-story storage park.

After physically opening some of the storage boxes, a clear understanding of the objects customers would store in the Z-boxes was developed. Large parts of the Z-boxes were filled with moving boxes which due to privacy reasons remained unopened. Things that were immediately visible mostly consisted of furniture, with a few Z-boxes containing a large number of books.

These findings show that the need for more storage is apparent in Deventer, which is precisely the benefit that a two-story storage park can bring. The things that people store show that two-story storage park must support a safe way to bring large and heavy items up to the top floor, and that a lot of weight has to be accounted for in the case of a Z-box filled with books. Further customer research will have to be performed in order to build a more detailed understanding.

2.1.4 Municipalities

Stacking the Z-boxes two high in order to increase profit is one thing, but it obviously needs to happen in a safe and legal manner. In the Netherlands, a permit is required to legally build a new structure, which this solution will likely be considered as. As the storage park is located in Deventer, the municipality of Deventer is a key stakeholder in the acquisition of this permit.

This permit ensures the structure is safe to use and can withstand various external loads and elements. To acquire such a permit, several safety documents have to be handed in. These will be further explored in a later section of this thesis. Figure 5 shows a visual representation of the different stakeholders involved in this project, and their respective ties to the main client.

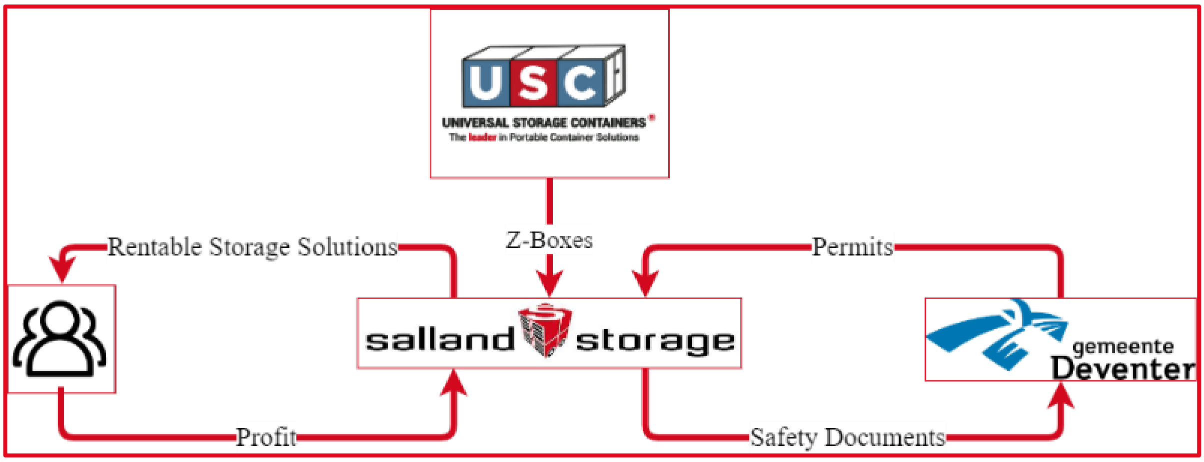


Figure 5: Visualization of primary stakeholders

2.2 The Z-box

As mentioned earlier, the Z-box and the self storage box are essentially the same product. To avoid confusion, the “Z-box” name will be the one used throughout the thesis. While they may seem to be basic, regular storage containers from the outside, the opposite is true.

One of the features that stand out is the versatility. This versatility is present in the form of different configurations that all consist of the same basic shape and frame. The main difference between the different models is the placement of the doors, and thus the division of the different rooms. These different models make sure that the customers’ needs are satisfied and can be found in Figure 6. The Z-box itself has dimensions of 5,87 m x 2,42 m x 2,41 m (L x W x H), while the dry weight of the boxes ranges from 1410 kg (model 1) to 1775 kg (model 6). The changes in these weights are due to the weight of the door structure. All of the Z-boxes have the same carrying capacity of 4535 kg.

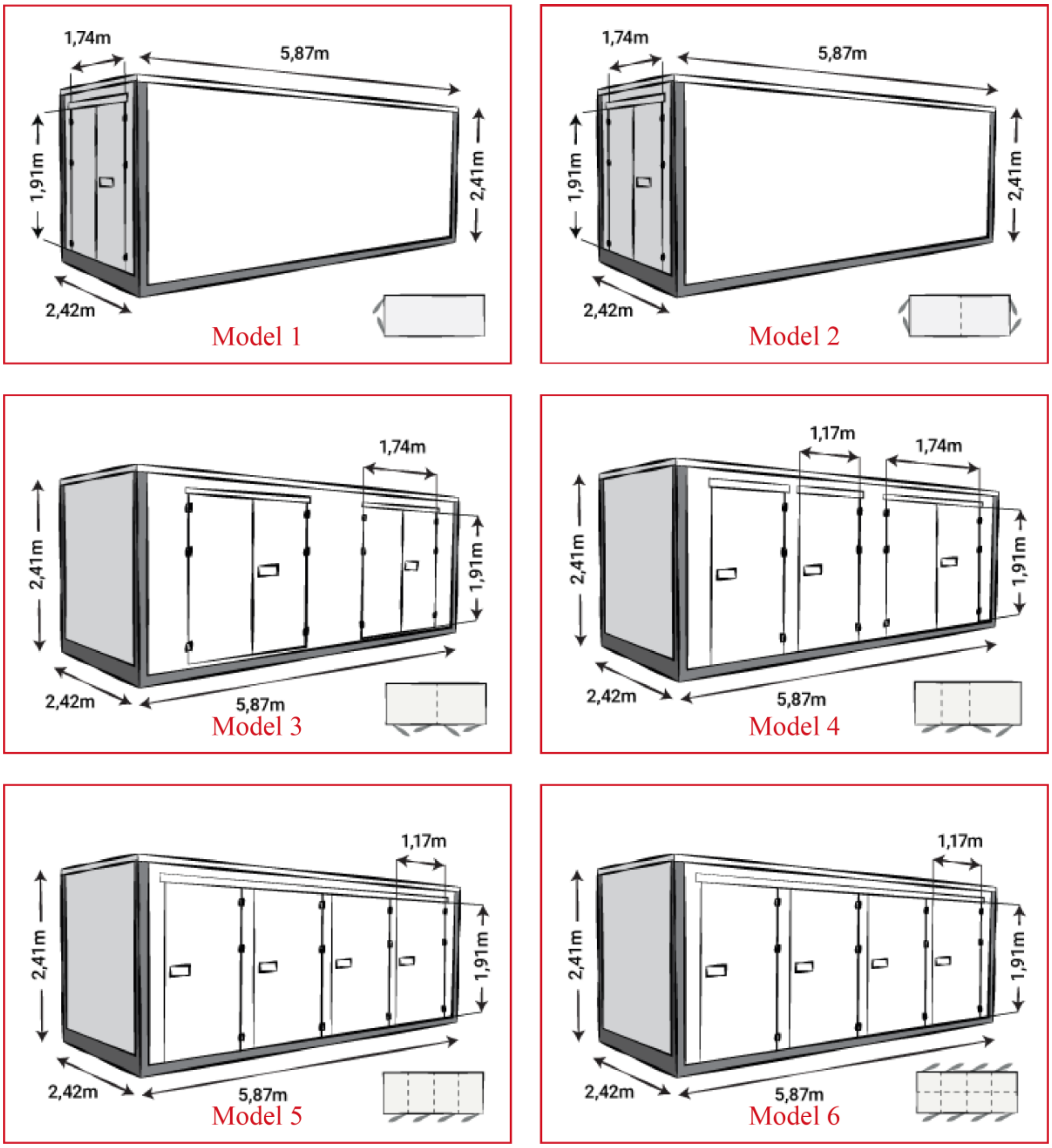


Figure 6: Different Z-box models

The other standout feature is the ease of transportation [6]. The boxes themselves can be folded up to bring the height down from 2.41 m all the way to 36 cm This allows a truck to either carry around 12 Z-boxes at a time, either in a shipping container or a flatbed. Both of these options help in reducing the cost of transportation. When the Z-boxes are placed at the desired location, they can easily be folded out again. The approximate time of setup, according to the client, is around 45 minutes.

Figure 7: Different methods of shipping the Z-boxes

The Z-boxes can also be stacked three high for storage, but this is only possible if the boxes are stacked with the corners resting on the one below as shown in Figure 8. According to the client, this has been tested and proven to be a sturdy construction. This layout results in a structure where the doors on the higher level can only be reasonably reached by using something like a ladder, which is not a viable method for the customers at Salland Storage who might be carrying heavy furniture.

As Salland Storage rents these boxes to customers in the form of parks, they might have to be moved to a new location after a certain amount of time. That is why the client stated that any developed solutions should aim to not alter the Z-boxes themselves in any way that would prevent them from returning to their original state.

Figure 8: Stacked Z-boxes

2.3 Prior theoretical work

The idea of stacking the Z-boxes is not necessarily a new one, and some work has already been done as an attempt to solve this issue. While the practical work will be handled later on, this section focuses on the theoretical research already performed. Analysing this theoretical research helps build a basis for the development of this two-story storage park. This basis allows the avoidance of both repeating the same work and repeating the same mistakes.

2.3.1 Bachelors' thesis

One of the available resources is a bachelor thesis project written by J. Smulders [7]. This bachelors' thesis was written in 2022 and is therefore of great relevance. Smulders wrote this thesis for USC, slightly contradicting this master's thesis which is written in service of Salland Storage. Still, the relevance of this thesis remains as it also concerns itself with stacking the Z-boxes. The thesis starts off with an analysis of the situation. Once again, USC is the main stakeholder here. The assignment is primarily concerned with designing a method of stacking the Z-boxes. The thesis shows the different stacking methods that could be used. Examples of these are the pyramid method, the bridge method, the overhang method, the bow method, and the plain stack method. These are depicted in Figure 9. The section is concluded with the notice that the bridge method was the best choice, with that one being put forward by USC initially.

Later on, the bridge method is explored further. Here, the main issue was analysing the load-bearing capacity of the overhanging Z-box floor, which would be an unsupported area. The analysis showed that this method is feasible in terms of this load-bearing capacity. At the same time, this concept also includes a way to protect the roof of the lower-level Z-boxes while simultaneously integrating fences for safety. These might be useful at a later point in this thesis.

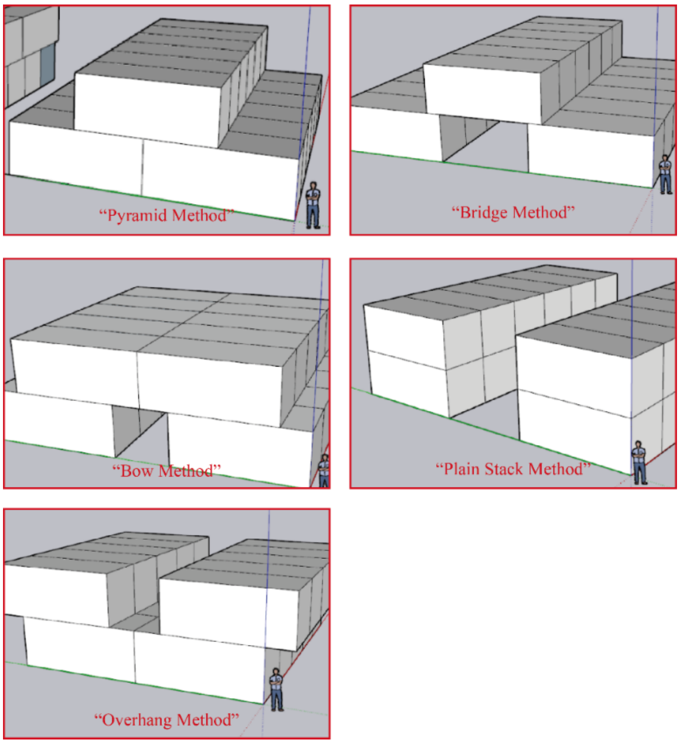


Figure 9: Smulders' envisioned methods of stacking [7]

2.3.2 Internal Report

Parts of the bachelors' thesis [7] were based on an earlier report [8] performed by one of the employees of Salland Storage. This report was also the reasoning behind the aforementioned preference of USC regarding the bridge method, as there were problems with the other methods.

It states that the 'bow' and 'overhang method' were too reliant on the balance inside the container. The plain stack method was also disregarded in this report due to the need for extra structures i.e., for walking around the storage boxes.

Continuing the exploration of the bridge method, the first consideration is of cars running underneath the bridge method. For this, the height of the bridge (2.4 meters) is compared to the height of a Volkswagen Transporter van. The conclusion is that most variants of these vans do fit, and due to the difficulties that come with raising either level, larger vans have to park at either end of the tunnel. The minimum width of the driveway is also set to 3.5 m, based on real-life observations. This does qualify as the absolute minimum, as the report mentions 4.5 meters as a more comfortable option.

The following section of the report focuses on building details, such as walkways, safety railings, bridges, and stairs. It starts off with a short analysis of the walkway surface located on top of the lower Z-box. Materials like rubber, multiplex, and plastic are proposed, but no choice is made. The walkway section does include a sketch that shows a top-down view of the different layouts that could occur on the top floor. This sketch is shown in Figure 10. Here, the red sections depict the stairs, while the green ones show the needed safety railings. The different options can all be implemented, with a notion that option B is more expensive due to the double stairs and takes away space in the back that could be used for an extra driveway.

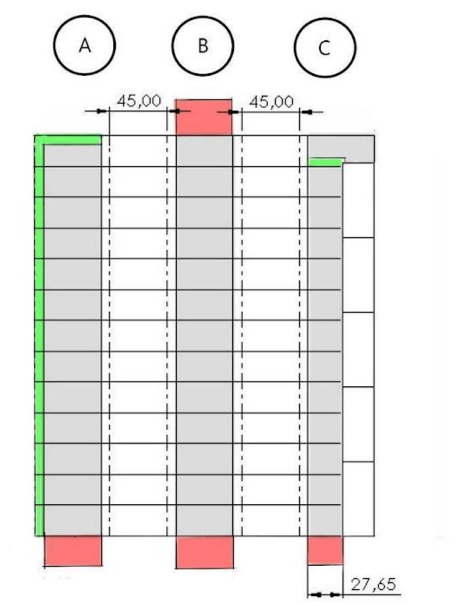


Figure 10: Top-down view of a possible layout [8]

The report also elaborates on the way to get to the second floor. Both stairs and lifts are considered, but the extra (likely permanent) structure needed for a lift quickly disregards it as no option. The stairs themselves are proposed to be the width of approximately 4.5 meters at their widest, with the reasoning being that this allows two people to comfortably lift heavy furniture up the steps. Suggestions are also made on how to avoid attaching the stairs permanently to the ground and/or the Z-box.

A case study is performed next, and this one is of great importance to this thesis as well. For this, the layout of a fictional, two-story container park is designed to be used in the storage park at Salland Storage. Normally, the number of Z-boxes that would fit in this space is approximately 52. With a two-story layout combining the bridge and pyramid method this number raises to 109, an improvement of 108%. The ground floor should then consist of either model 1 or model 2 Z-boxes, with the doors on either side of the Model 2 providing maximum profitability. The driveway underneath the bridge would in this case be 4.5 meters, with a height of 2.4 meters. A one-way traffic policy is also proposed to manage the traffic flow. Safety is another thing of concern in this report. Bollards, speed thresholds, and a height limiter are put forward to safely manage the cars underneath the containers. Figure 11 shows a sketch that combines the different considerations mentioned before.

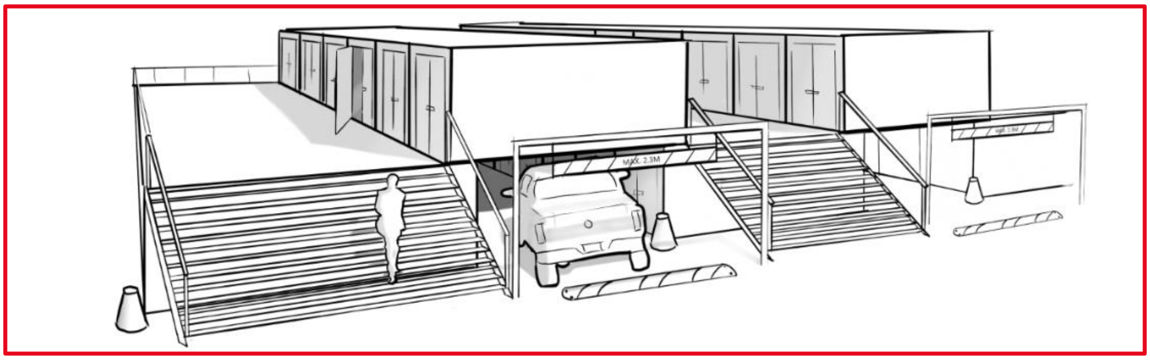


Figure 11: Sketch of envisioned two-story storage park

2.3.3 Structural report USC

The other source that is of relevance for this thesis would be the structural analysis report of the Z-box [9]. This structural report is based on the American structural report by USC and is commissioned by the USC office located in Deventer. It summarizes the development process of the Z-box itself. At the start, a set of requirements is laid out, on which the Z-box would be rated. Important parts of the report focus on the testing of the Z-box, in which several static loads were tested and measured. This structural report therefore provides a great deal of information regarding the static load-bearing capabilities and can be referenced throughout this thesis. At the same time, the report also contains a set of shop drawings that can prove useful when calculating static load tests in several different configurations. One interesting note is that the structural report assumes that the Z-boxes are stacked with the same orientation, meaning that the load-bearing vertical structures are all in one axis. In that case, it reports a field test with a static load of 11.800 kg without "excessive deflection or permanent deformation."

2.4 Prior practical work

The research performed in the earlier reports [7], [8] did continue afterwards. Figure 12 shows a layout that combines the findings in both of the reports. This image was created by Salland Storage, to serve as a visual aid in their real-life testing.

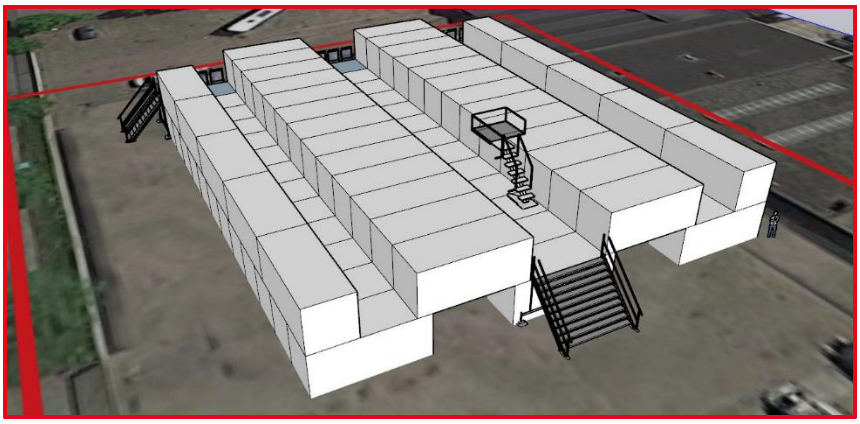


Figure 12: Testing Layout Deventer

2.4.1 Stacked Z-boxes

At the moment, two Z-boxes are already stacked at the storage park in the 'bridge' configuration, and a few Model 5's are lining the edge.

They are empty at the moment, and further analysis needs to be done on the carrying capacity of the floor. While this was researched in the bachelors' thesis [7], some floor changes have been implemented since then, which compromises the validity of the previous simulations. Currently the feet of the z boxes are resting on 40 cm x 40 cm rubber tiles with a thickness of 7 mm. The top Z-boxes are not fastened to the bottom ones in any way.

Figure 13: Z-boxes stacked at Salland Storage (2023)

2.4.2 Stairs

Right at the beginning of this thesis, stairs were installed at the site in order to test not only the usage of the stairs, but also the assembly process.

The stairs themselves were delivered by a company called Easystairs [10]. They are attached to the Z- boxes with an L-bracket that is put on the lengthwise side of the lower Z-box. Currently, this bracket is not attached to the Z-box, but rather laid on top (Figure 15).

As an improvement, a new L-bracket will be delivered that will be bolted to one of the threaded holes located along the roof edge.

Since the ideal height of the stairs slightly exceeds the height of the Z-boxes it is attached to, the stairs are angled forward slightly. While it might seem minor at first, it is noticeable when walking on the stairs, and thus could put people off balance when moving heavy things. To solve this problem, a proposal was put forward to heighten the L-shaped bracket. This would coincidentally also heighten the stairs to match the walkways on top.

Figure 14: Stairs installed by Easystairs

Something that is also worth mentioning is the fact that the stairs are placed in between two Z-boxes, with a width of around 1 meter. This contradicts the wider stairs considered in the internal report [8]. When asking the client about this, the reasoning behind this choice was; “Extra wide stairs, custom made, are expensive. Also, the stairs might be 4 meters wide, but the door of the Z-box is still a lot smaller. Thus, the wider stairs were disregarded.”


Figure 15: Current L-bracket holding the stairs

The stairs themselves also might need some slight improvements. It was noticed that the room underneath the stairs might be an issue when people drop things in between the steps. This could be solved by adding something like a net at the bottom, but this will be explored later on.

2.4.3 Bridge

At the same time that the stairs were installed, a bridge was installed as well. It is located in between two Z-boxes that have already been stacked in the 'bridge' configuration. A steel beam is installed underneath the bridge, resting in the holes located at the bottom of the two Z-boxes. The bridge itself is being supported on either end. It can be seen in Figure 16

2.4.4 Walkways

Parts of the walkway are in place as well. The top layer consists of the same rubber tiles as used to support the feet of the Z-boxes. Underneath these rubber tiles are perforated plastic blocks, that allow the water to drain away underneath the tiles.

2.4.5 Railings

During some of the earlier work done on the research for the two-story storage park, a basis for a railing has also been designed. It currently consists of a set of aluminium beams that can slide in and out of each other to alter the total length and angle of the railing. It is attached to the bolts on the corners of the Z-box. These railings can be seen in Figure 17. .

Figure 16: Bridge installed in Deventer (2023)

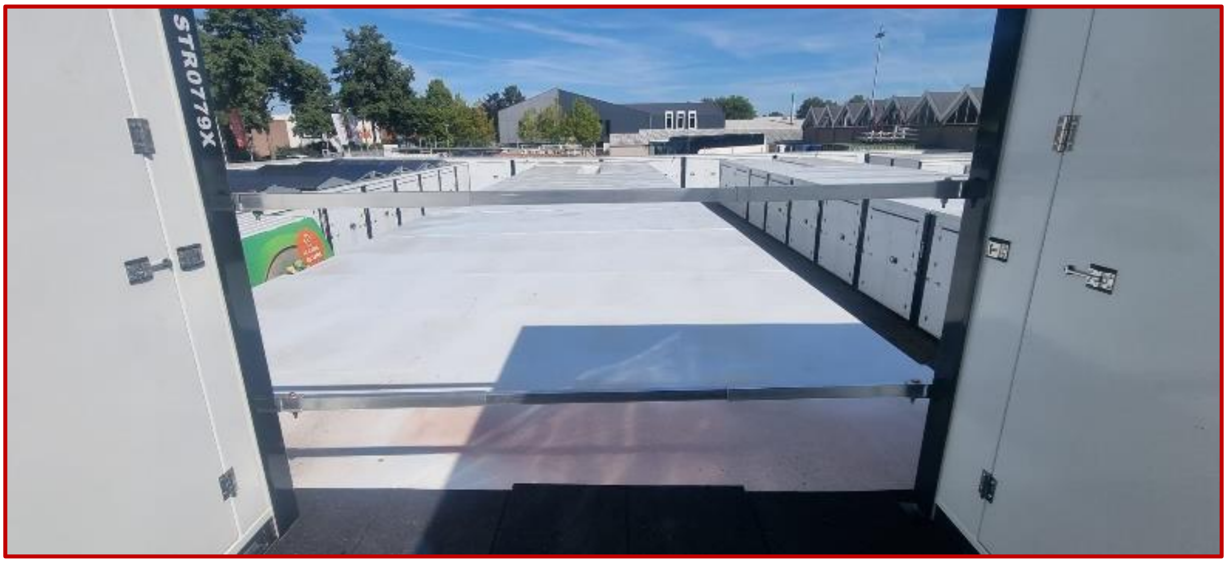


Figure 17: Railings installed in Deventer (2023)

2.5 Conclusion

This entire exploratory chapter aimed to define the progress that has been made with regards to building a two-story storage park prior to this thesis.

2.5.1 Summary

Several stakeholders came forward in this section that will have to be kept in mind during the development. Not only are the needs of the actual customers of importance, government bodies such as the municipality are also of concern. The entire two-story storage park will be built up out of different models of the same storage box, called the Z-box. Several projects had already concerned themselves with stacking the Z-boxes. Salland Storage proposed 5 different configurations, shown earlier in Figure 9. A bachelors' thesis was performed on this subject [7] which concluded that either the bridge or plain stack method had the most promise. Another internal report [8], performed some time earlier, ditches the plain stack method in an earlier stage of the design due to the need for extra structures. When consulting with the client for clarification, it became clear that the decision for ditching the plain stack method was the correct one.

The internal report proposes instead to stack the Z-boxes sideways along the edges, with the bridge method making up the middle section. This maximizes the storage capacity and removes the need for safety railings along the edge.

The storage park in Deventer is already used as a testing ground a future two-story storage park. Here, two Z-boxes have been stacked in the bridge configuration, even with an extra walking bridge in between. Other things that are undergoing testing are the stairs, a walkway bridge, and rubber tiles supported by plastic sheet for water drainage.

2.5.2 Points of attention

The following (basic) points of attention for the two-story storage park can be brought forward from this section. As not all of these points of attention have a way quantifiable nature, wording them requirements is avoided.

- The two-story storage park needs to be profitable.
- Instructions for stacking the Z-boxes need to be present.
- Construction time must be minimized.
- The Z-boxes on the top floor must be able to carry heavy loads.
- The two-story storage park must include a safe way for the customers to move large and heavy items such as furniture to the top floor.
- A permit of the concerning municipality (Deventer) must be acquired to declare the park as safe and legal.
- The Z-box cannot be altered in any way that would prevent them from returning to their original state
- The two-story storage park must avoid the use of movable stairs.
- The two-story storage park must make use of the 'bridge' method.
- The top floor does not need to be heightened to make space for larger vans.
- The minimum width of the driveway must be set to 3.5 meters
- The second floor should be accessible by use of stairs instead of lifts.
- Custom stairs or bridges should be avoided due to the extra cost

3 Research

Some of the points of attention brought forward in section 1.5.2 can be further clarified by performing research. This section will focus on the legislation and safety aspects concerned with acquiring a permit from the municipality. On top of that, the profitability is researched by utilizing two key aspects; the market research and the layout optimalization. Not only will this section provide requirements for the remainder of the thesis, but the layout research will yield the key areas that need focus during the simulation. A visual representation of this can be seen in Figure 18.

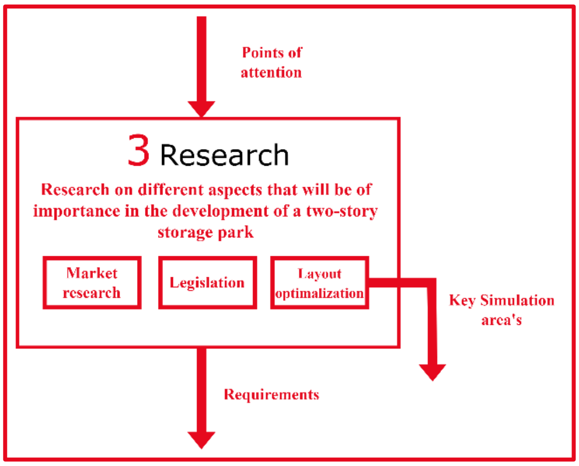


Figure 18 Plan of approach - Research

3.1 Legislation

One of the most important things to consider about this entire design is the legislation on load bearing structures. After all, if the Z-boxes are not legally allowed to be stacked, there is no thesis to be done. On top of that, if the structure passes legal requirements, it can also be declared as safe. The starting point of this project lies in the storage park located in Deventer, and as such Dutch legislation is first looked at.

3.1.1 Eurocode

One of the first things to consider about the Z-boxes in order to determine the proper legislation is what they are classified as. While they are not directly attached to the ground below, they are in contact with it. The "(Model-) bouwverordening (1.1.) " [11] classifies a 'bouwwerk' as a structure that is supported by the ground. At the same time, a building is classified according to the 'woningwet' as a 'bouwwerk' that is accessible by humans while forming a (partially) enclosed space. [12] Therefore, the Z-box is legally considered a building, and building legislation has to be taken into account.

Luckily, the EU has drafted construction standards for buildings in the EU. These will be taken into account. [13] In article EN1991-1, also called Eurocode 1, the actions on structures are defined. The areas that allow people to walk around like the walkways and stairs, fall under category C4 "Areas with possible physical activities". This would be the moving of for instance furniture in the case of a two-story storage park. One of the recommendations for this category states that the area should be able to withstand a load of 5 kN/m^2.

For storage areas, the situation is a bit different. "Areas susceptible to accumulation of goods" fall under category E1. EN1991-1 gives a recommendation of 7.5 kN/m^2, but this is not a required load. It states that these values may be changed if necessary according to the usage for the particular project. This is interpreted in this context as being allowed to add a weight limit.

3.1.2 Municipality permit

As the aforementioned building legislation has to be considered, one must also apply for a permit to build it. This can be done on the "omgevingsloket" website [14]. When going through the checklist, the website shows that an "omgevingsvergunning" or permit is needed. In order to get a permit that allows Salland Storage to stack the Z-boxes, several documents have to be handed in to the overseeing municipality. These documents are summarized below :

- Data on (tunnel) safety
  - General Safety
  - Tunnel safety
  - Fire safety
- Data on outlook of structure
- Data on functionality of the structure
- Data on sustainability
- Data on equality of buildings

Some of these documents can be left aside for now, as stacking the Z-boxes does not impact the sustainability of them for instance. Distilling the data down gives us the following aspects to work out:

- Load-bearing simulations
  - Tunnel & General Safety
- Layout
  - Fire Safety (escape routes)
  - Functionality of the structure
  - Outlook of the structure

The 'Outlook of the structure' document based off of the "Data on equality of buildings" and is of particular importance to this thesis. As building this two-story storage park is not necessarily a mundane permit (in contrast to a shed for instance), the equality of buildings document is likely applicable. This document is used in case it does not meet the exact guidelines of the law, but is similar in safety, usefulness, and sustainability. In that case, the permit can still be handed out. It should also be noted that the load-bearing simulations might be performed again by an external company for the municipality, but his does not mean that the ones performed in this thesis will be of no use, as it vastly increases the chance that the permit is received in a timely manner.

3.1.3 Construction laws

The other custom section of the two-story storage park will be the railings closing off the walkways. Keeping the "Data on equality of buildings" in mind, they can be compared to the railings closing off balconies. Article 2.14 [15] of the 'bouwbesluit' states that a railing is needed if the edge of the walkway is at least 1 meter of the ground. As the Z-box and thus the walkway on top has a height of around 2.4 meters, this is the case in the storage park. Table 2.14 [15] shows that the height of the railing needs to be at least 1 meter. Regarding the gaps that are allowed to be present in the railing; the park can be classified under a structure that has a logistical function, meaning that according to Table 2.14, the gaps can be 0.5 meters wide. However, smaller gaps might be preferred in the case of this storage park.

3.1.4 Safety factor

There are a variety of sources that all cite different safety factors for buildings. The initial idea was to follow the same reasoning of the structural report [9]. It mentions the 203.5MPA stress on the roof rafters to be safe, as the yield stress on the rafters is 235 MPA. This would then coincide with a safety factor of approximately 1.15. This safety factor was removed in consultation with the client however, due to a simple reason. The legislation required a sustained pressure of $5kN/m2$. This is the equivalent to more than 5 people per square meter, or over 40 people per roof. According to the client, this number of people will never be present at one time in the storage park. Therefore, the decision was made to remove the extra safety factor.

3.2 Profitability

One of the points of attention stated in section 2.5.2 states that the park must be profitable. Profit can be defined as the following formula [16]:

PROFIT = REVENUE-EXPENSES

Therefore, two main things that need to be considered in order to maximize profitability are maximizing the revenue and minimizing the expenses. This correlates to the following factors in the case of stacking the Z-boxes:

Maximizing revenue	Minimizing Expenses
User demand	Resource costs
Maximizing the usable Z-boxes	Assembly difficulty – and thus man hours

Table 2 Maximizing the profit

These different factors will need to be dissected and researched separately. In the case of maximizing the revenue, an analysis can be done by performing market research. At the same time, researching the maximization of the usable Z-boxes can be done by performing an analysis on the different layouts that can be utilized. This is not the case for the minimization of the expenses however. At the current state of progress, clear and concise expense studies cannot be performed at this stage. Analysing the resource costs and assembly difficulties can only be done in a satisfactory manner if there is a basis for both of these aspects. Therefore, both of these points serve as guidelines, which can be called upon during the development section.

3.2.1 Market research

Generating revenue is only possible if there is something to rent or sell for customers to pay for. This supply/demand relation will also be used in the task of maximizing the revenue. As any product or service brought to market, the user demand has to be sufficient in order to sell it. In the case of stacking the Z-boxes, this can be defined as the willingness to use the second floor. Two things are of importance here; the general usability of using the second floor, and the overall user experience. To fully optimize the usability of the structure, one needs to know what the user experience is like. To research this, a questionnaire was sent out to a set of customers. This questionnaire was sent out to a set of customers that were currently renting a storage box at the location in Deventer. 11 Customers responded, which might seem a bit low. However, the population size of customers in Deventer is 60, and following the formula for determining sample size [17], a total of 7 people would already be representable. Therefore, the decisions were made to treat these answers as representative. All of the relevant questions and full answers can be found in Appendix A. The main takeaways of this market research were:

- Around 30 customers visit their Z-box each day
- A visit lasts an average of 21 minutes.
- Most customers at Salland Storage rent a Model 2 or a Model 1
- Almost all customers consider their storage box at minimum ‘mostly filled’
- Customers saw issues with loading and unloading heavy items
- Customers would not be willing to pay the same for a storage box on the top floor

3.2.2 Optimal layout

In order to maximize the profits, the amount of Z-boxes per square meter needs to be maximized. This means that not only an optimal layout has to be envisioned that can be used for new storage parks, but also a more adaptable layout that is able to accommodate the storage parks already in service. The analysis performed in this section will also provide some of the key simulation area's that will have to be considered at a later stage.

While the internal report [8] did consider different configurations for the layout of such a storage park, it had no real test to verify the outcome. The report assumes a fictional area of 48 m x 48 m, which vaguely matches the area in Deventer. This area contains 52 Z-boxes and has unobstructed driveways of 4.5 m in width. A sketch of this area is shown in Figure 19.

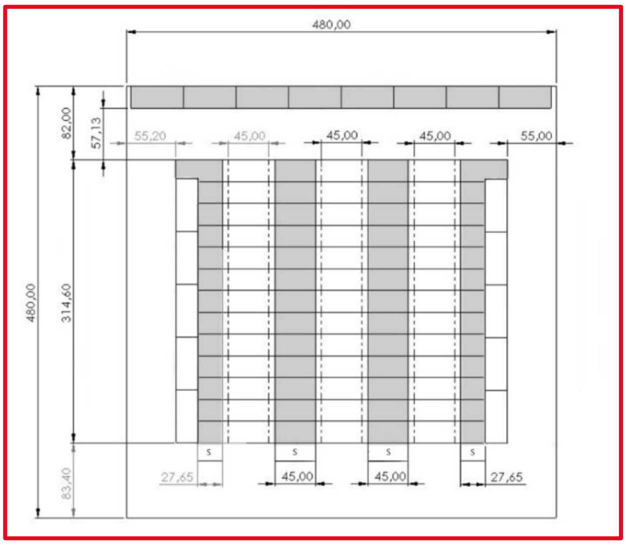


Figure 19: Top-down view of possible layout [8]

To predict the effect of building a two-story storage park more accurately, a slightly different approach than used in the report will be used. First of all, real world data will be used to draw the storage park in Deventer, with the Z-boxes drawn as they are placed currently. This layout is used as a baseline, where only small alterations will be allowed.

In a second analysis this same area is stripped of Z-boxes completely, to see what the effect of stacking the Z-boxes would be if it were to be considered during the start of a new storage park.

For both of these situations, some rules have to be taken into consideration. These rules are composed from the findings in chapter 2, and have been created in collaboration with the client:

- The structure must have an unobstructed driveway of *at least* 3.5 meter in width.
- The walkways need to have a width of at least 2 meters.
- The stairs need to be near the entrance of the area.
- When adapting an existing storage park, no more than 10 percent of the current containers can be moved.
- A margin has to be taken into consideration for stacking the Z-boxes, as they won't always line up perfectly.
- All Z-boxes should be reachable from only one stairway, to ensure flexibility on the ground floor, and to keep the costs down. (As stairs are more expensive than bridges.)
- The bridges can not span more than 5 meters.
- The driveway must have a circular flow, meaning that no car would have to reverse to get out of the storage park.

Optimizing an existing layout

The model for the current layout of the ground floor in Deventer was a combination of Google Maps data, and real-life measurements. This model was created in the CAD software Solidworks [18], so that different configurations can be built in 3D. A comparison between the two can be seen in Figure 20.

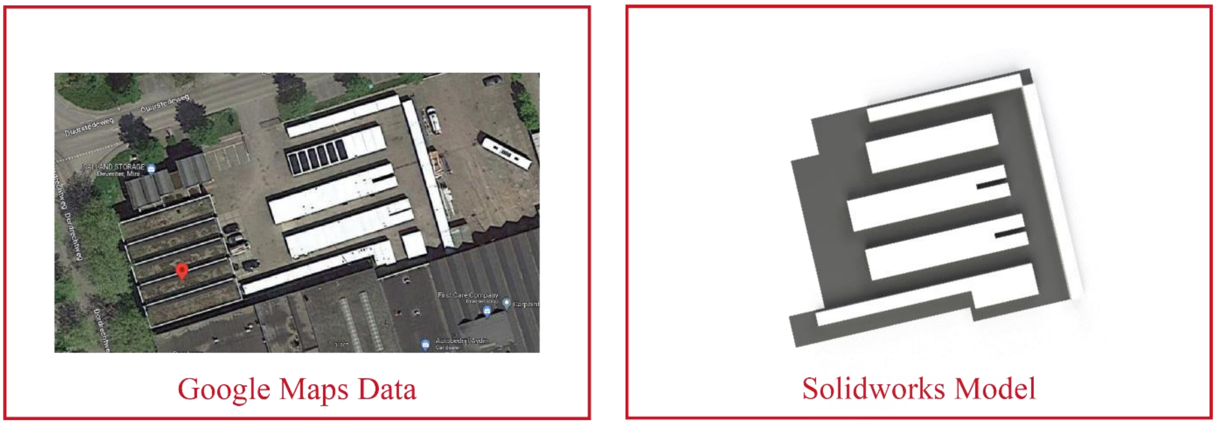


Figure 20 Comparison between real-life data and the Solidworks model

As creating this optimal layout is mostly trial-and error, the different steps will be shown in sequence. When simply filling the top space by only keeping the bridges and stairs into account, the layout as shown in Figure 21 can be envisioned.

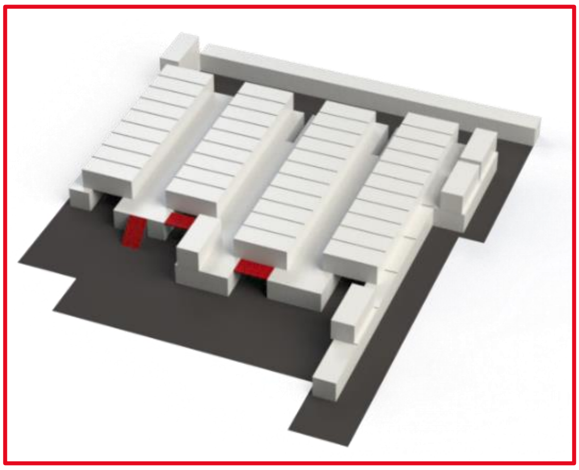


Figure 21 First Layout iteration

In this configuration, 45 Z-boxes could be stacked on top, making the total 97. This configuration does not take the width of the walkways into account however. Some walkways, especially the ones on the outer edges, are not 2 meters wide in this configuration. Taking that into consideration reduces the total amount of Z-boxes from the aforementioned 97 down to 91.

There is also room left at the sides of the stairs that can be utilized for stacking Z-boxes. Combining these findings would result in the layout as shown in Figure 22 .

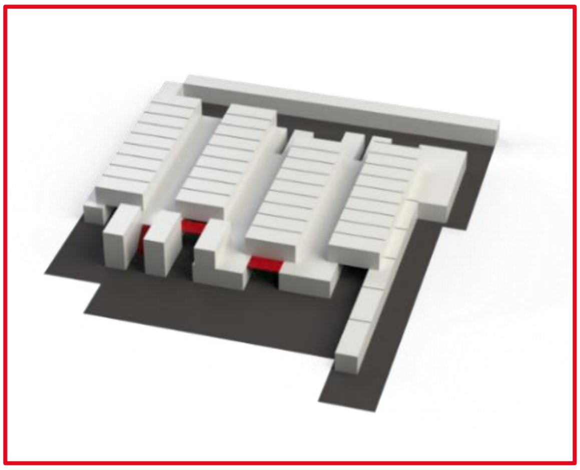


Figure 22 Second Layout Iteration

Here, the total number of Z-boxes is 95. One thing to note is that the outer two rows can only be Model 1 Z-boxes (see Figure 6), with the door on the crosswise side facing inward. This does reduce the flexibility of the upper floor, and most likely the number of customers.

When swapping these Model 1's for Model 5's, the following configuration as shown in Figure 23 can be created. While this configuration does have a lot more flexibility due to the Model 5's, the number of Z-boxes is reduced from 95 to 87.

These different iterations have revealed few things:

- The space on the top floor can be utilized to its maximum efficiency by facing the crosswise sides of the bottom Z-boxes to each other, instead of the lengthwise sides.
- There is a recurring pattern of the Model 2's bridging over the driveway, which is broken up due to the walkway bridges.
- Due to the 'locked' configuration of the bottom floor there is a lot of wasted space, something that could be solved by taking the second floor into consideration from the beginning of constructing a park.

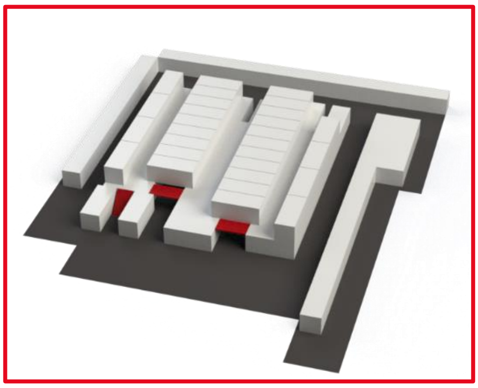


Figure 23 Final layout iteration

Optimizing a new layout

The lessons learned from the previous iterations can be used to draw an optimized layout when taking it into account from the beginning of constructing the storage park. When taking the aforementioned observations into account, the following base layout can be drawn:

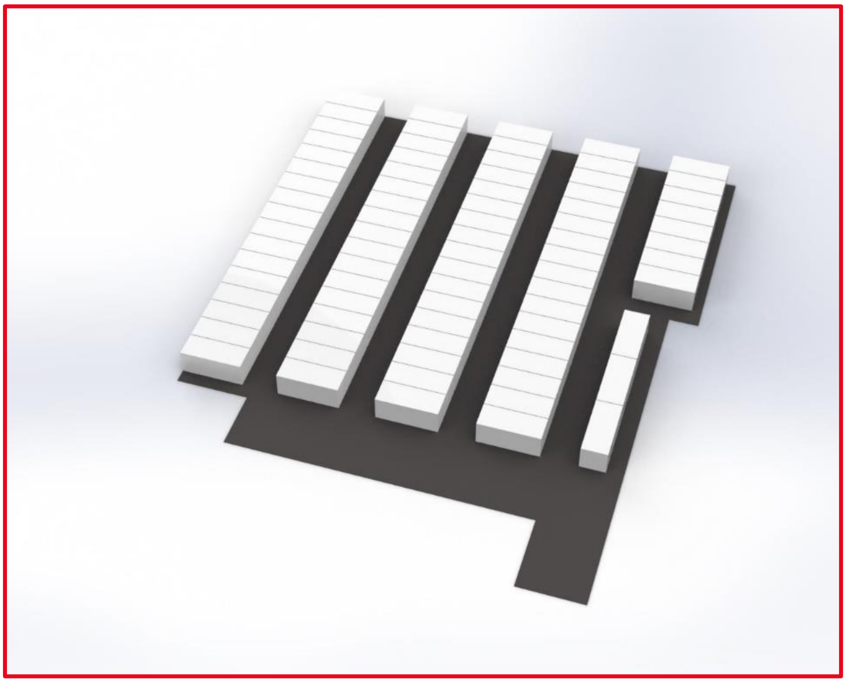


Figure 24 Optimal base layout

This layout ensures that the number of Z-boxes that face each other on their crosswise side is maximized. The total amount of Z-boxes on this floor would be 64. However, the layout yet does not consider the cars' circular driveway. Taking these two things into account, a second floor here would then look like the one as shown in Figure 25.

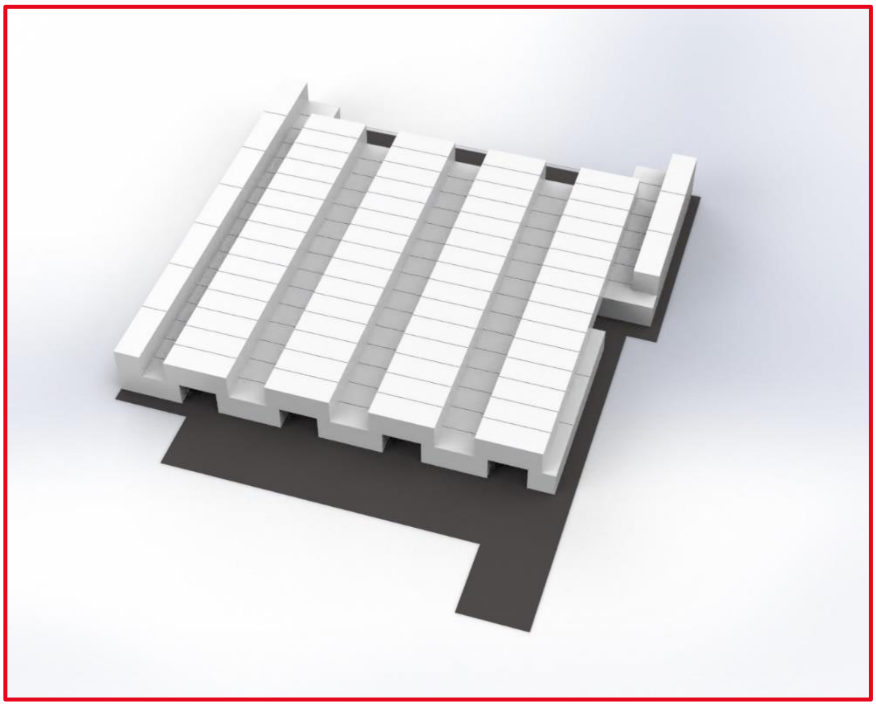


Figure 25: Optimal top layer

This configuration raises the total number of Z-boxes to 118. As can be seen on the figure above, bridges and stairs still have to be added. The basic rule of thumb seems to be that each bridge takes the space of one Z-box. This would result in a loss of 4 Z-boxes. The stairs themselves can be flanked by 2 Z-boxes, offsetting this loss slightly. This depends on some things though; When flanking for instance a 1.5-meter-wide staircase, the total width would be $1.5\,m + 2.41\,m + 2.41\,m = 6.32\,m$. This would result in the Z-boxes sticking out around 30 cm on each side, reducing the width of the driveway. So, this solution can only be implemented if either the width of the sideway is already sufficient, or if the stairs have a maximum width of 1 meter. It should be noted that this is also the current width of the stair being tested in Deventer, and this seems sufficiently wide.

Secondly, stacking on top of those 2 Z-boxes would be possible, but in order to reach the front side of those boxes, one of the Z-boxes hanging over the driveway would have to be removed. It was decided that that was not worth the effort.

The pattern that emerges when taking the stacking into account from the beginning is nearly the exact same that was envisioned in the internal report [9]. It seems that this report had the right idea from the beginning. That layout would only fit in a square area though. In areas like the one in Deventer, this layout could still be implemented by covering the remaining space in a custom pattern, specific to the needs of the park. This is also shown on the right side of Figure 25. After presenting this layout to the client, he requested that the Z-boxes need to be attached to one another. The reasoning behind this is that with their experiences with permits, it will aid their case. This is kept in mind going forward. Now that a clearer understanding of the layout is developed, a safety analysis can be done on some of the uncertain areas. This should result in an even more defined set of guidelines for the layout of the storage park.

3.3 Requirements

With the findings discovered in this chapter, the points of attention put forward in section 2.5.2 can be elaborated upon. This section aims to further bring them towards clear and concise requirements. Obviously, with a project of this scale, it is difficult to narrow each small detail down to a set of requirements. Thus, only two requirements have been defined, spanning the profitability, safety, and legality of the two-story storage park. These are supported by key considerations that should guide the process in the development of this two-story storage park towards achieving them. The key considerations are a combination of the earlier written points of attention, as well as the new findings in this particular chapter.

"The profit of a two-story storage park per m^2 should be higher than a one-story storage park."

This requirement should be achievable by taking note of the following key considerations:

Minimizing the Expenses

- The construction methods should focus on minimizing the construction time.
- Instructions for the construction of a two-story storage park the Z-boxes need to be present.
- The Z-box cannot be altered in any way that would prevent them from returning to their original state.
- The construction methods should focus on minimizing the amount of material.
- Peripherals such as stairs and bridges should be bought off-the-shelf.

Maximizing the number of usable Z-boxes per m^2

- The driveway must be at minimum 3.5 meters wide.
- The crosswise sides of the model 2 Z-boxes on the bottom layer should face each other.
- The area over the driveways should be populated with bridging (model 2) Z-boxes.
- The sides of the top floor should be populated with (model 5) Z-boxes.
- A margin has to be taken into consideration for stacking the Z-boxes, as they won't always line up perfectly.
- The stairs should not exceed a width of 1 meter.

Optimizing the usability

- Customers should not be deterred from using the park due to safety concerns.
- The walkways need to have a width of at least 2 meters.
- The distance from entrance of the area to the stairs should be minimised.
- All Z-boxes should be reachable from only one stairway.
- The driveway must have a circular flow, meaning that no car would have to reverse to get out of the storage park.
- The second floor should be accessible by use of stairs.
- There should be a price difference between the first and second floor to account for the added difficulties that come with a unit on the top floor.

"A permit of the concerning municipality (Deventer) must be acquired to declare the park as safe and legal."

This requirement should be achievable by taking note of the following key considerations:

- The area's that will support people need to be able to carry a load of $5kN/m2$
- The lower Z-boxes should not collapse under the weight of the top layer
- The railings closing off open areas should have a height of at least 1 meter.
- The gaps in the railings closing off open areas should not exceed 0.5 meters.
- The structure should be able to withstand external forces, such as wind, snow, rain.
- The Z-boxes should be attached to one another. (Client)

4 Experience compass

The profitability requirement is accompanied by a rather vague key consideration:

"Customers should not be deterred from using the park due to safety concerns."

The feeling of safety is inherently a subjective one, making this consideration a difficult one to validate. To help with this, a tool will be created in this section that should allow someone to quantifiably indicate which feeling they would want to instil in a design. This tool can then be used to alter the design of some functional elements of the two-story storage park to improve the user experience. First the tool itself will be defined, followed by the literature research that will support the tool. Lastly, the preferred feeling that the client wants to instil on the customers will be defined.

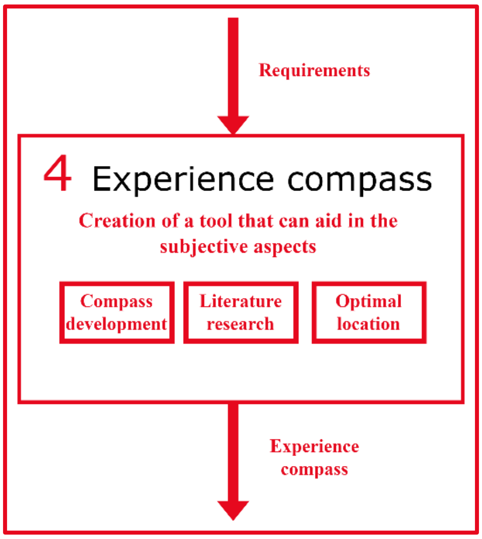


Figure 26 Plan of approach - experience compass

4.1 Definition

As mentioned above, the tool that will be developed should allow a user to quantifiably indicate the feeling that their design should instil. The base design of the tool will be a two-axis graph, as this should allow one to easily visualize the effect of changes on a design. The design of this graph is loosely inspired by the political compass used during elections in the Netherlands as seen in Figure 27. The reasoning for this is that the political position of a party on this compass is also not a fully defined position, but a rough estimation. This matches with the uncertainty behind defining a subjective feeling. So, in this case the location on the graph indicates the user experience instead of a political standpoint. The two axes for such an experience compass can be defined as follows:

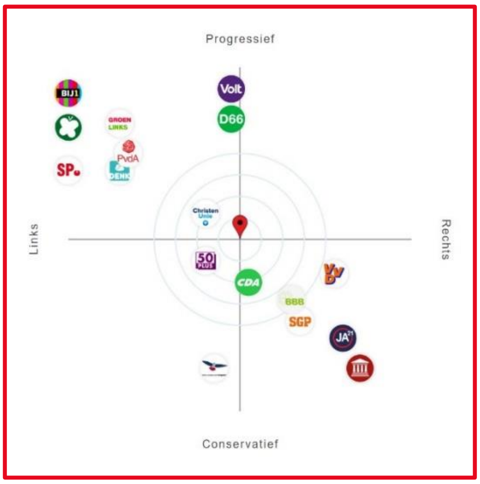


Figure 27 Political compass

Appearance: this axis will range from a toy-like appearance such as a playground, to an industry rated appearance, such as scaffolding.

Feeling: this axis will focus on the feeling of the customer, ranging from unsafe and uncomfortable, to safe and comfortable.

The combination between these two axes should allow the client to pick a proper balance between both the way customers perceive and experience the storage park. For instance, one might feel that a highly industrial structure will feel very safe. Consider a scaffolding, however. While it is an industrially rated structure, and it might make people feel it is safe, a lot of people would not be comfortable walking on it. On the opposite side, a playhouse might make people feel completely safe and comfortable but might give the customer a false sense of freedom, or simply not align with the clients' values. An example of where some structures *could* be placed is shown in Figure 28.

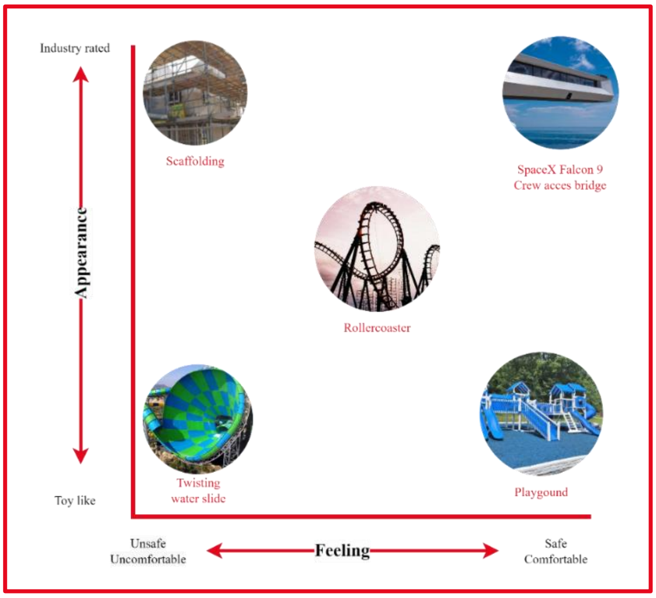


Figure 28 Example of experience compass diagram

4.2 Literature research

Now that the tool itself has been defined, both of the axes will need to be supported by literature research in order to establish an empirical basis for the definitions. While this matter is subjective as mentioned earlier, there needs to be a way to quantify it on the experience compass. Therefore, the conclusions that will come forward out of the literature research will be adapted so that they can be placed on one – or both – of the axes. Due to the fact that these adaptations cannot be theoretically supported, the locations on the axis can be viewed as a gradient location, not an absolute one.

A look is first taken at human perception of these design. As the majority of the materials used in the development of the two-story storage park have a functional purpose, there is no focus on the human perception of these materials and designs. Obviously, a lesser functional material is not going to be used to improve the designs' perception, but there are alterations possible in the outer shell of the design. These could be in the form of coatings, caps, etcetera.

Design is able to reach humans through all of their senses, namely vision (sight), audition (hearing), olfaction (smell), gustation(taste), and tactition (touch). For the design of the two-story storage park, the only sensations that can reasonably be influenced, are the vision, audition, and tactition. Thus, that is where the focus of this research lies. These three senses, combined with some other theories, are used to theorize the possible ways that the customers' feeling of safety can be enhanced.

4.2.1 Vision

The visionary part of the design is able to be split up into multiple sections that could be of importance. Colour is one of the most important parts in how a design gets received. Normally, brand recognition plays an important role in the decision-making process. The issue in this case is that the base colour of Salland Storages' brand is red. Red is universally seen as the colour for danger or stop [19]. At the same time, green is seen as the colour for safe, and go. This means that on one end of the axes will be the 'warning colours', and on the other end of the spectrum would be playful colours such as green and blue. Next to colour, the other thing that aids in the perceived safety due to the visionary sensation is the shape of the designed peripherals. While some parts of the design are set due to off-the-shelf components, small modifications can be installed. The initial idea was to eliminate all sharp corners, and thus make the design come across as more 'friendly'. However, while circular shapes do incite approachability, friendliness, etc, angular shapes incite a feeling of toughness or strength [20]. Adapting both of these findings to the earlier defined axes would result in Figure 29 .

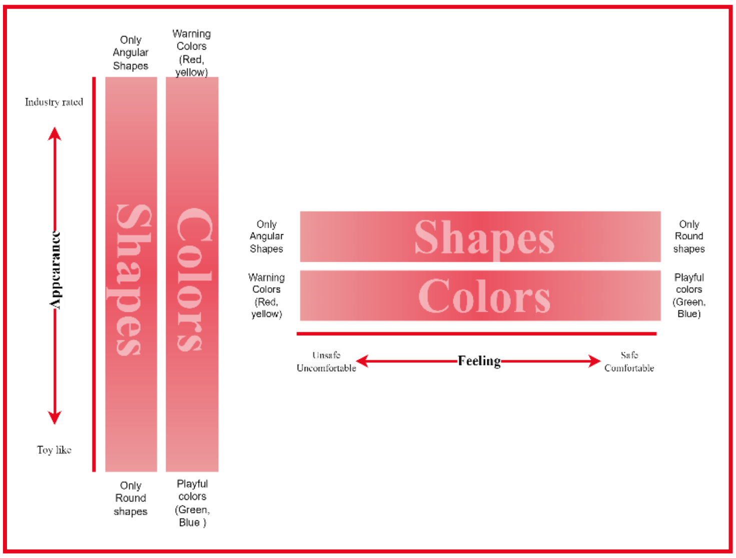


Figure 29 Vision defined on the experience compass

4.2.2 Tactile

There are two main components that the tactile design will be based upon. The first will be the feeling of actually touching the product, and the second will be the walkability, or standing on top of the product. Stainless steel is often already used to show the robustness, elegance, and premium quality of a product [21]. A majority of plastic or polymeric parts are perceived by people as toy-like, with a smaller part being associated with professionalism. Using too much plastic would likely result in an increase of comfortable feeling, but simultaneously decrease the amount of professionalism & sturdiness [22]. The walkability of the peripherals is mostly of importance for the walkways, stairs, and possible bridges. The main factor of concern here would be the movement that people experience when walking on top of these peripherals. Large amounts of movement can mostly be found in toy-like structures, yet it will make people feel uncomfortable when it is not expected. Both of these aspects can be seen visualized on the axes of the experience compass in Figure 30.

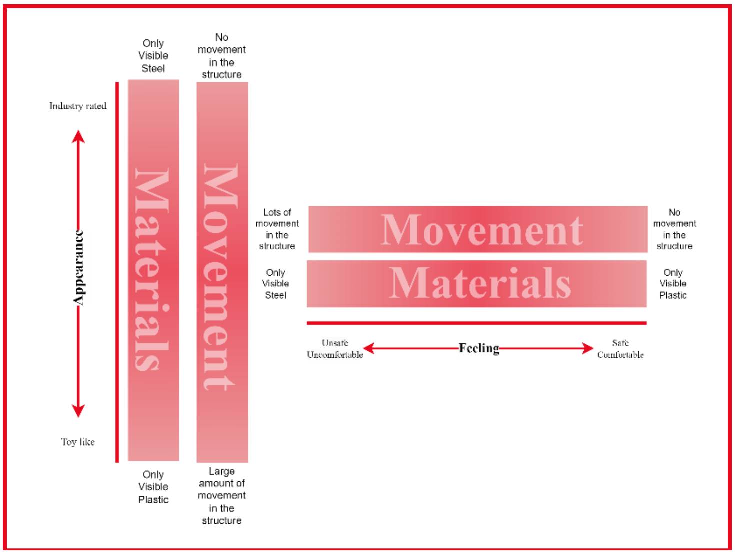


Figure 30 Tactition defined on the experience compass

4.2.3 Audition

The two main components describing the auditory section are the structure's static noise, and its dynamic noise. To clear this up, the 'static' noise would be the noise that the structure could make while on its own (i.e.) creaking due to the swaying in the wind, with the dynamic noise being the sound due to walking on the bridge for instance.

Noises such as creaking can impress the user that the quality of the product is bad, or in the case of the two-story storage park, unsafe [23]. This will be the case for both the static and the dynamic noise. As the static noise is already considered in the minimization of movement however, only the dynamic noise is considered here. Figure 31 shows the implementation on the experience compass.

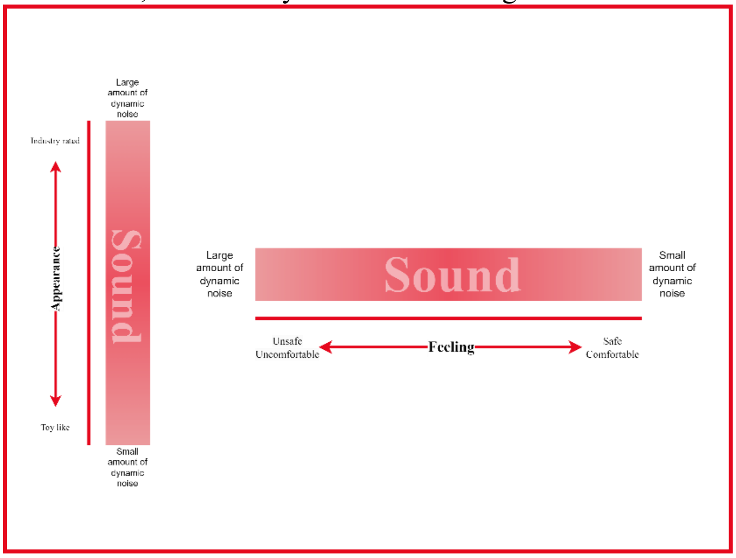


Figure 31 Audition implemented in the experience compass

4.2.4 Fear of height

Some other stimuli could also have interesting effects on the customers' feeling – even though they might not be classified under a specific main sense. An example of this would be a fear of heights. Humans tend to experience fear and dizziness by being exposed to heights [24]. On top of that, humans perceived danger also rises in response to a fear of heights [25]. This mostly presented itself in a manner where people would have irrational feelings about some things that could happen – for instance the entire structure collapsing. Since there were no sources that mentioned a change in appearance of a structure due a fear of height, only the feeling was considered. This can be seen in Figure 32.

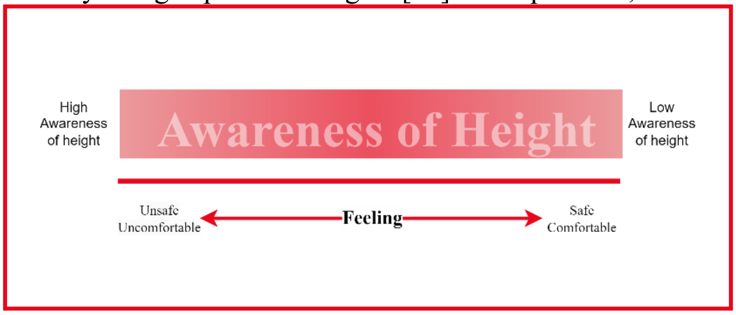


Figure 32 Awareness of height implemented in the experience map

4.2.5 The prospect-refuge theory

The last source for this research is a paper on the prospect-refuge theory [26]. There have already been guidelines prior to the experience compass that aim to capture a positive emotional response, one of these being the prospect-refuge theory. This theory was created by Jay Appleton in 1975 [27]. Appleton proposed that people aim to fulfil a desire when reviewing a space – such as their home or a storage park. The prospect part of the theory refers to the opportunities the people want to feel, while the refuge refers to a safe space.

Humans perceive spaces differently based on a variety of factors. The paper aims to solve this by combining the results of 34 studies to examine the influence of the following 4 factors: Prospect, refuge, mystery, and complexity. The results show that the need for open view (prospect) is mostly of significance for interior settings, which the top floor of the two-story storage park could classify as. A minor amount of complexity in interior spaces is also preferred. Both the refuge as well as the mystery aspects yielded contradictory results and have thus been left out of the experience compass. Figure 33 shows the implementation of the complexity & outlook into the experience compass. Once again, there was no data on the influence on the appearance of the structure, and thus it is only considered for the feeling axis.

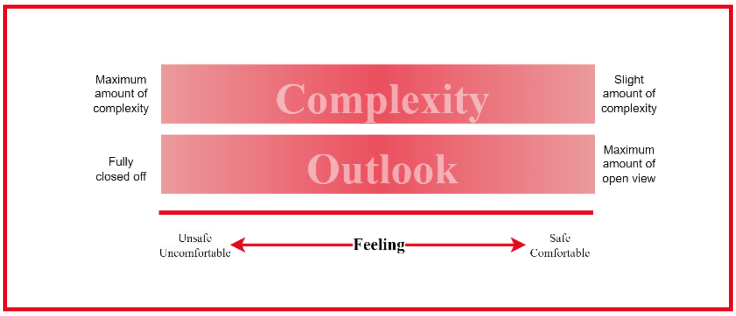


Figure 33 Prospect-refuge theory implemented in the experience compass.

4.2.6 Summary

Combining all of the different research into the two axes results in Figure 34. Once again, the bars displayed here are not absolutes, as they have been adapted from their empirical backing to fit on the experience compass.

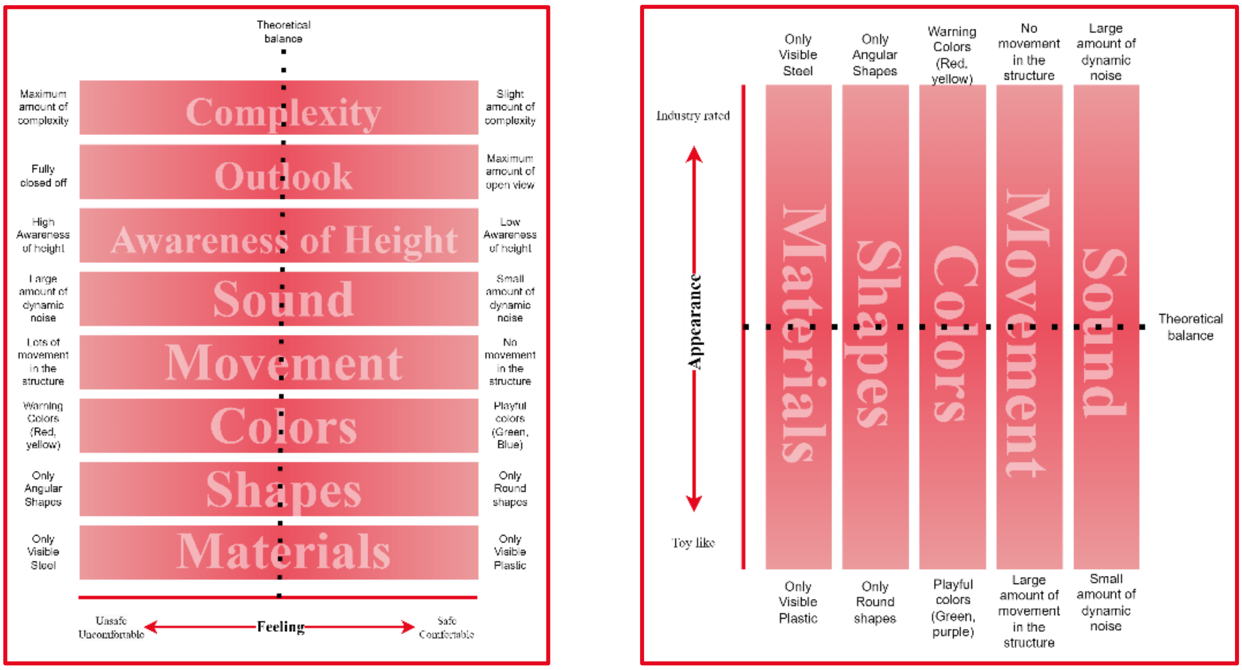


Figure 34 Literature research combined on the axes

4.3 Optimal location

The optimal location on the experience compass is dependent on the one responsible for the design, as that will be the person that determines the feeling that they desire to be instilled on the user. A short analysis was also done on the cost difference when moving the optimal location around the compass. This effect was not considered in this thesis, due to the fact that minimizing the expenses will already be considered during development. The cost analysis can still be found in Appendix B.1.

In the case of this two-story storage park, the compass is set up in such a way that it needs to be filled in by the primary stakeholder: Salland Storage. Both of the CEO's were asked to independently mark their desired spot in the experience compass. The average of both can be seen in Figure 35. Their independent answers can also be found in Appendix B.2.

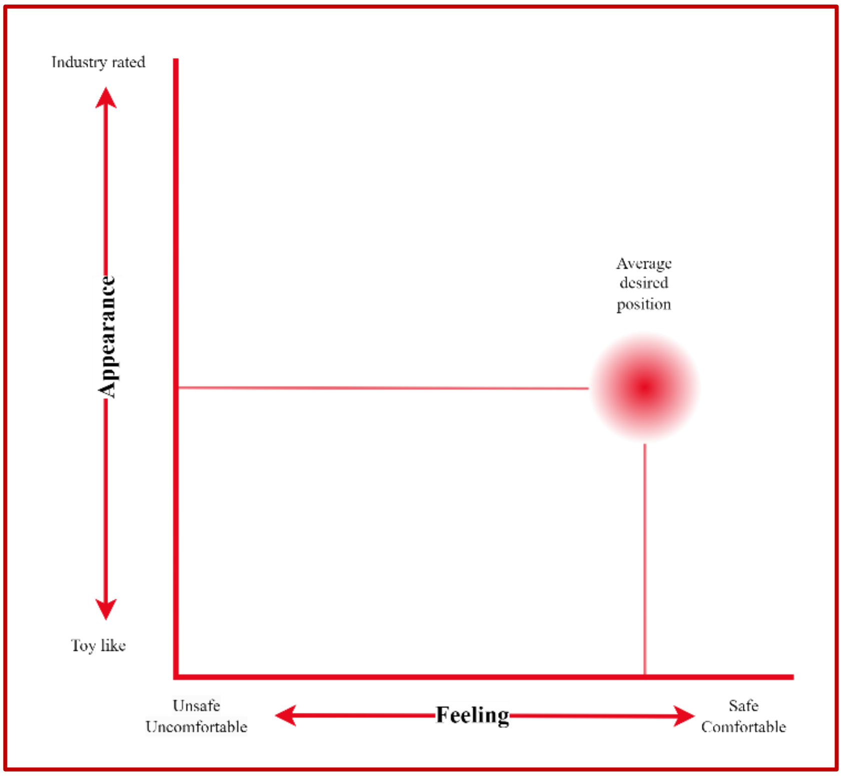


Figure 35 Optimal Subjective location as shown on the graph

4.4 Conclusion

The aim of this section was to create a theoretical basis for a rather subjective situation. While the literature research performed did show a few pointers regarding design changes and their influence on the customers' feeling, there was no real concise method. That is why the experience compass was created in this section. It is supported by the aforementioned literature research, even though the conclusions of said research have been adapted to fit on the experience compass. The effects of these adaptations should come forward when evaluating the use of the experience compass at a later point. Due to this uncertain nature of this experience compass, it will not be formulated to a full requirement, but will rather be tested by adapting certain objects during development.

5 Simulations

Two of the relevant key considerations that came forward out of the chapter 3 are shown below.

The area's that will support people need to be able to carry a load of $5kN/m^2$.

The lower Z-boxes should not collapse under the weight of the top layer.

This section will aim to simulate both of these. The layout research performed earlier revealed the key area's that can be used to set up the different situations that need to be simulated. A visual representation of this section can be seen in Figure 36.

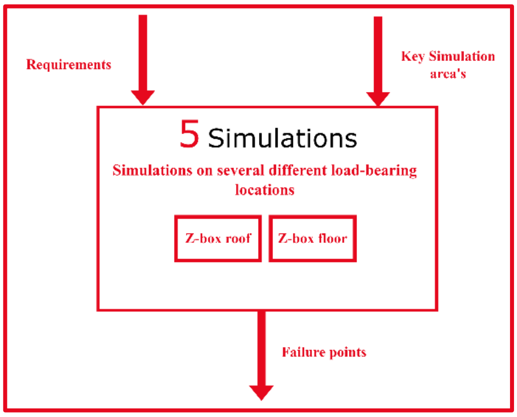


Figure 36 Plan of approach - Simulations

Simulating the different situations is done by using SolidWorks, which was already used to model the different components of the Z-box. On top of that, it includes a package called SolidWorks Simulation, which can be used to perform load-bearing calculations on the drawn components. One of the most important things to consider for the load-bearing simulations is the material that is used in the frame of the Z-box, named Q235 [9]. The full properties of this Q235 material can be found in Appendix C.

5.1 Z-box floor

As the earlier envisioned lay-out for the two-story storage parks has (model 2) Z-boxes hanging over the driveway, an analysis needs to be done on the load-bearing capacity of the floor. This section thus focuses on the Z-box floors as shown in red (Figure 37), and similar ones. Such an analysis has been performed earlier [7], but during that time the floor structure of the Z-box has been changed as shown in Figure 39 , making the earlier simulations inaccurate. The updated SolidWorks model can be seen in Figure 38.

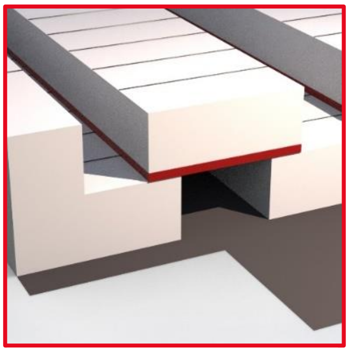


Figure 37: Floor of the overhanging (Model 2)

Figure 39 Floor changes

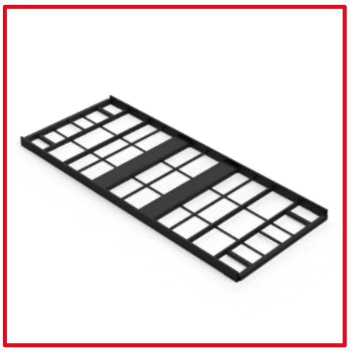


Figure 38: Model of new floor

5.1.1 Set-up

Setting up the simulation in SolidWorks requires the user to set up a few steps. One of the things that is crucial for the simulation are the different weights and forces at play.

The rated carrying capacity of the Z-boxes is 4535 kg. The weight of the model 2 Z-box minus floor itself is approximately 1400 kg. This is calculated by subtracting the weight of the flooring from the weight of the entire model 2 Z-box (1650 kg) [6]. The weight of the floor can be derived from the SolidWorks model itself. When applying the Q235 material described above, SolidWorks calculates a mass of 242 kg.

That means that the maximum rated total weight pushing down on the frame is equal to $4535kg + 1400kg = 5935kg = 58222N$.

Next, the location of the lower Z-boxes that support the floor need to be defined. Normally, the floor of a Z-box rests on 6 feet that are evenly divided along the sides. This time the middle part of the Model 2 floor is hanging over the driveway below. That means that only the 4 corner feet will be supported, and thus treated as fixed sections(Green arrows in Figure 40). Lastly, the forces need to be applied. In SolidWorks, this can be done by simply adding the weights and a gravity force. In this case, that would be 4535 kg for the floor, with 1400 kg on the long- and crosswise edges of the frame.

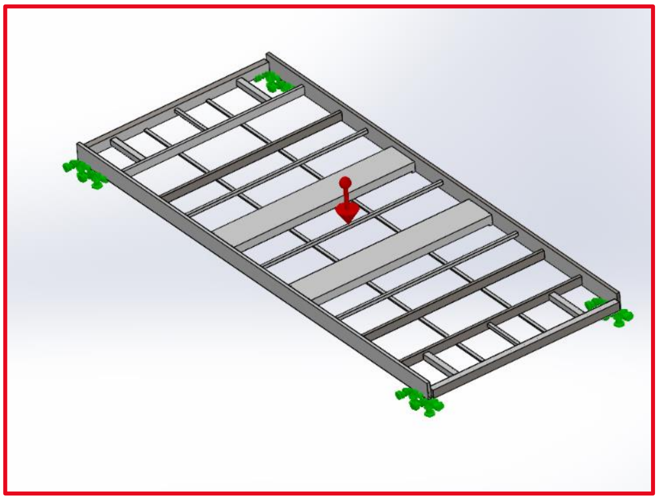


Figure 40 SolidWorks Simulation Setup

5.1.2 Result

The main thing to consider for the structural integrity of the flooring is the stress exerted on the frame. Q235, the steel used in the frame, has a yield strength of 235 MPA. Running the simulation shows a maximum von Mises stress of approximately 337 MPA. This means that, with the Z-box loaded to its maximum capacity of 4535 kg, the floor will collapse. It should be noted that buckling of the floor is not of concern here, due to the vertical pillars inside the Z-box walls.

While the result of this test might seem disappointing, it does provide valuable information; either a redesign or a set maximum capacity is required. This redesign and/or a possible weight limit is something that can be worked out in the development phase.

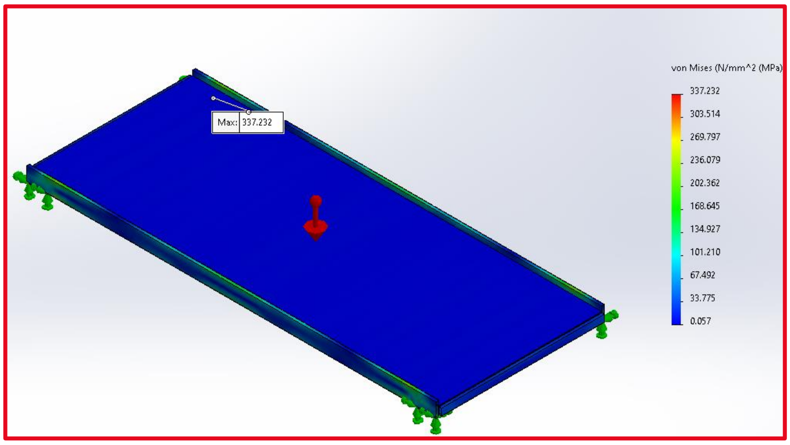


Figure 41 Result of floor simulation

5.2 Z-box roof

When stacking the Z-boxes on top of each other, the lower Z-box roof serves as the main foundation to the top layer. Thus, in order to figure out if the Z-boxes can be stacked on top of each other, an analysis needs to be performed on the load-bearing capacity of the Z-box roof.

The construction drawings for the roof of the Z-boxes were retrieved by contacting the metal factory that produces them, and can be found in Appendix D. Unfortunately, the included CAD files were corrupted, and thus the model had to be remade in order to perform the analysis.

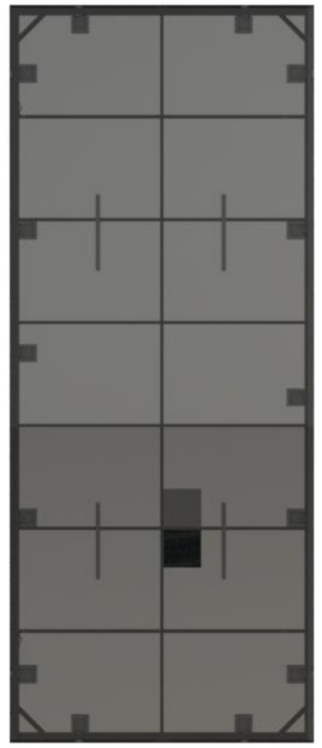


Figure 42 Image of roof model

5.2.1 Set up

As the entire model of the roof consists of roughly 90 components, without even counting the screws, it needs to be simplified. The load capacity of the roof is created by a steel tubing frame, supported by vertical beams along the Z-box walls that prevent buckling. Laid on top of this steel tube frame is a single piece of 1.2 mm thick sheet metal. This sheet metal needs to be included in the assembly, as it transfers the loads to the steel tubing frame. The same principle goes for the rubber walkway on top, which will also help in spreading the load.

Components like the led light tubes do not add any meaningful load bearing capacity and can thus be represented as added weight to the frame. The load analysis considers these added weights as a force pulling down on the frame (i.e., gravity). Table 3 shows the components that were removed, and their respective weight.

	Amount	Total weight
TPU Plate	1	100 kg
FLS Plate	2	50 kg
Sheet metal tabs	14	4 kg
Outer Sheet metal	4	10 kg
Various components	42	55 kg
Total removed weight		219 kg

Table 3 Removed components

After this model was stripped down the Solidworks simulation can be set up. There are a few steps that are of importance.

First of all, the materials had to be defined. The flooring for the walkways were set to general rubber. The frame and sheet metal top were once again set to the Q235 steel. Some standard loads could now also be applied. While Solidworks does calculate the gravitational force acting on the drawn components, the model has been simplified. This means that the weight of the removed components is added as a separate force. The legislation explained earlier state that the total carrying capacity needed for the walkways on the roof is 5 kN/m^2, so that force will also have to be added.

5.2.2 Verification

While the Solidworks model of the roof is accurately drawn, it needs to be verified due to its rather complex structure. The structural report of the USC [9] reveals some clues that could be of use for this verification. First of all, a real-life load test was performed which simulated snow on the roof of the Z-box. In this test, a load of 2314 kg was applied, which resulted in a deflection of 38 mm, and a maximum stress of 203.5 MPA. When applying this same load on the Solidworks model, the deflection measured 38.2 mm, and the stress was 206 MPA. It was thus concluded that this simulation correlates sufficiently to the real-world.

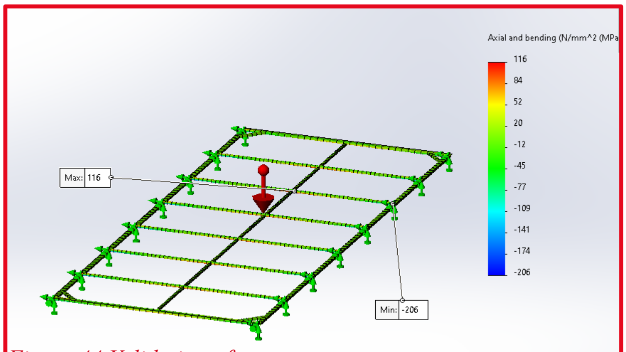


Figure 44 Validation of max stress

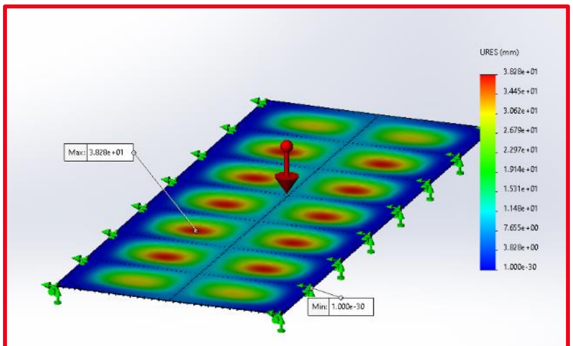
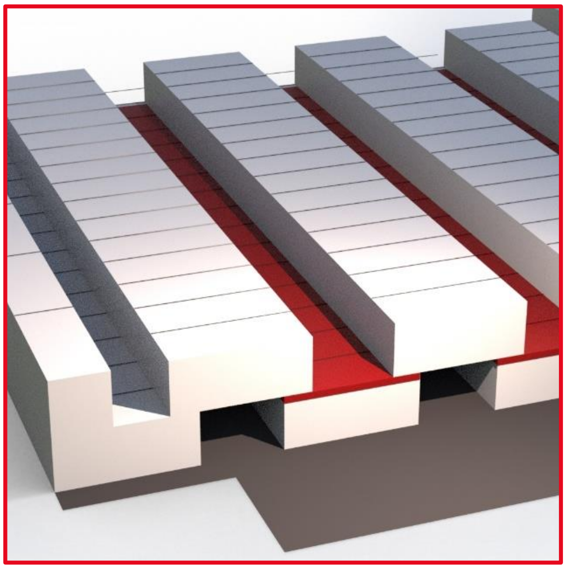
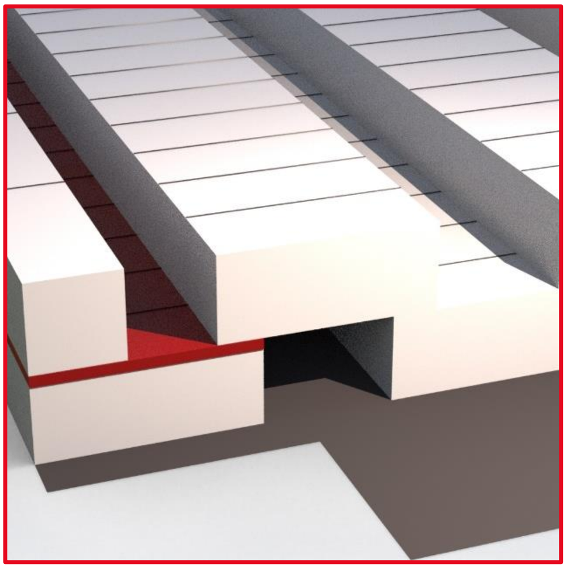


Figure 44 Validation of max displacement

There are two general situations that will have to be simulated. The first situation is at the roofs where the Z-boxes are hanging over the lower walkways, and the second situation will be at the edges of the park. Both of these are shown in Figure 45, with the relevant roofs pictured in red.



Situation 1



Situation 2

Figure 45: The two situations that will require simulations

5.2.3 Situation 1

This situation is once again shown in Figure 46. As stated in the key considerations earlier, the driveway in between the Z-boxes will be at minimum 3.5 meters, and at maximum 4.5 meters. With the length of the Z-box being at 587 cm [2], it means that the upper (model 2) Z-box will be supported in the range from 68 cm to 120 cm inward from the roof. In the current test layout in Deventer, the feet of the Z-box are rested on 40 cm x 40 cm rubber tiles, which can further spread the load.

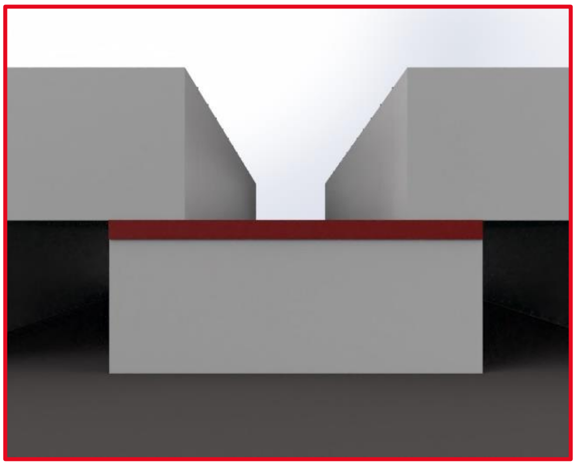


Figure 46 Situation 1 of the 'bridge' configuration

The research on the optimal layout performed in section 3.2.2 showed that the models that will be used will be Model 2's and Model 5's. In situation 1, the roofs that are supporting the overhanging Model 2 will be considered. According to the website of USC [6], the empty weight of this type of Z-box is 1650 kg, with a load capacity of 4535 kg. While the previous floor simulation in section 5.1 did show that in its current form, the floor will not support filling the Z-box to its maximum capacity, this can still happen in a later stage with a possible redesign. Therefore, this 4535 kg is still used here. In the best-case scenario, the feet resting on the lower Z-box will be perfectly in line with its frame. In that case, it might seem that a simulation is not necessarily of importance, as the structural report [9] showed that the (corners of the) frame could carry 11800 kg. This load was divided over the 6 feet of an upper Z-box, evenly spreading the load. However, the lower Z-box in the bridge situation is not carrying 6, but only 4 feet on its frame. This would in turn concentrate the load more. Therefore, the simulation first focuses on estimating the carrying capacity of the rest of the frame, to see if it could carry the weight concentrated on the 4 feet. One of the stakeholders is the assembly crew that set up the parks, and while they might be skilled workers they are still prone to error. On top of that, not every location lends itself to perfectly stack the boxes. Lastly, a walkway bridge might shift the Z-boxes surrounding it sideways. Due to this, the possibility of it resting on the rubber walkway on top of the sheet metal roof will also be included. Considering all of these cases, the following simulations will have to be performed for situation 1.

Feet Resting Positions	On edge frame	On rubber walkway	On middle of roof frame
68 cm inwards	Simulation A	Simulation C	Simulation E
120 cm inwards	Simulation B	Simulation D	Simulation F

Table 4: Different simulation setups

Results

The following forces were applied for each of the simulations:

- Legislative required pressure of 5 kN/m^2
- Gravitational force
- Weight of removed components
- Weight of the rubber walkway
- Weight of the overhanging model 2 Z-box filled to its maximum capacity.

The results of the simulation can be seen in Table 5.

	Maximum deflection	Maximum Stress	Pass/fail
Simulation A	69.6 mm	866MPA	Fail
Simulation B	53.9 mm	783MPA	Fail
Simulation C	560 mm	560MPA	Fail
Simulation D	220 mm	800MPA	Fail
Simulation E	46.2 mm	1573MPA	Fail
Simulation F	46.0 mm	1501 MPA	Fail

Table 5 Simulation results - situation 1

This result once again confirms that in its current form, stacking the Z-boxes while filled to their full capacity will cause the structure to collapse or fail. After all, the maximum stress in the beams is nearly double the rated capacity of the Q235 steel in every other place on the frame. This means that another solution will have to be found.

5.2.4 Situation 2

The second situation takes place at the edges of the proposed layout. Two model 5 Z-boxes will rest on those roofs, in a perpendicular relation. The opposing Model 2's in the bridge configuration will be simulated at the position of simulation B in the previous section, since this gave the best result.

As the feet of the Model 5's at the edge can be located somewhere along the entire width of the Z-box, simulating every possibility is an unreasonable amount of work. Therefore, only a select few cases will be simulated, on which the conclusion can still be drawn. The three cases that will be considered are shown in Figure 47, where the grey boxes indicate the feet position. Here, the rubber walkway is still included in the simulations as it is able to spread the load more evenly.

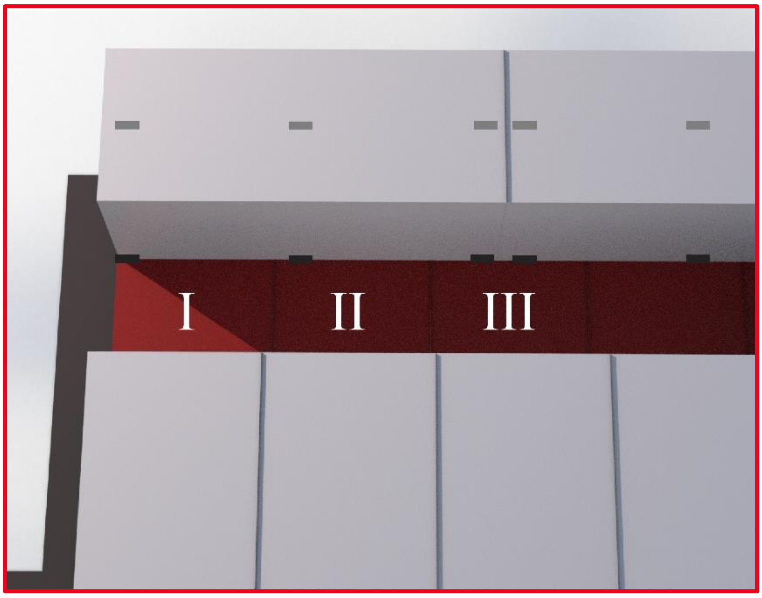


Figure 47 Situation 2 visualized

The following forced were applied for each of the simulations:

- Half of a model 2 Z-box, filled to its maximum capacity.
  - $6185kg/2 = 3092.5kg$
- Model 5 fully loaded
- Rubber Walkway
- Legislative required pressure ($5\ kN/m2$)
- Weight of the removed roof components

	Maximum deflection	Maximum Stress	Pass/fail
Simulation I	31.2 mm	706MPA	Fail
Simulation II	90.2 mm	949 MPA	Fail
Simulation III	89.2 mm	1770MPA	Fail

Table 6 Simulation results - situation 2

These simulations show that currently, the lower Z-boxes will not be able to carry a fully filled Model 5 on top.

5.3 Conclusions

The simulations performed in this sections showed that extra steps are needed in order to stack the Z-boxes without them collapsing. When filled to their max capacity, the floor of the overhanging Model 2 will fail, and the roof supporting the upper Z-boxes will also collapse. While this could be 'solved' by just lowering the storage limit inside the top Z-boxes, a storage limit will also impact the profitability of the top floor. The next chapter will, among other things, aim to improve the storage capacity of the top Z-boxes.

6 Development

Now that the specific problems that need solving have been identified, the development of solutions can commence. This section will aim to solve the failure points that came forward during the simulations, join the Z-boxes as stated in the key considerations, and implement the experience compass created in section 4. All of this can be seen in Figure 48.

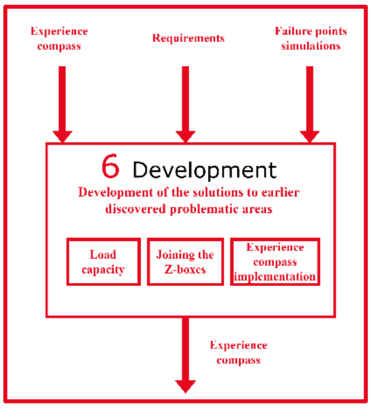


Figure 48 Plan of approach - development

6.1 Load capacity

The following key consideration will be taken into account during section.

- *The area's that will support people need to be able to carry a load of* $5kN/m2$
- *The lower Z-boxes should not collapse under the weight of the top layer*

Figure 49 Feet of a Z-box

In chapter 5, the simulations showed that the roof frame of the Z-box would not be able to hold the upper Z-boxes while fully loaded. This does not match up with the structural report by USC, which showed that the roof of a Z-box could carry 11800 kg. This weight was divided more evenly over the frame however, which spread the load. The approach of spreading the load over the frame more evenly is also one that can be implemented in the case of building a two-story storage park. With that in mind, the feet of the overhanging model 2 Z-box can be lengthened, spreading the load over the frame of the lower Model 2. This would be the cheapest option requiring a minimal amount of extra development work. These feet can be seen in Figure 49.

6.1.2 Lengthening the feet

The approach of lengthening the feet can be tested by simply altering the simulations done earlier. In the case of the floor, the main issue of it failing is the large unsupported section overhanging the driveway. Currently, the feet under the Z-boxes have a length of 30 cm to spread their load over. This can be lengthened to up to 120 cm, as to simulate a 3.5 m driveway. A comparison between these 30 cm feet and 120 cm feet can be seen in Figure 50. To determine the effect of lengthening the feet on the stress of the floor, several simulations are performed.

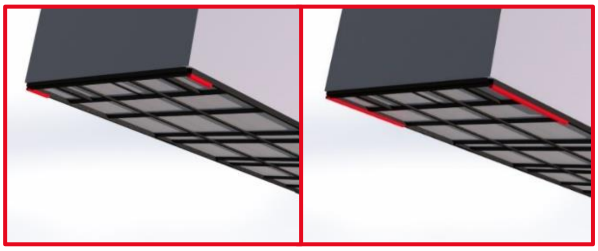


Figure 50 Comparison of lengthened feet

Effect on the floor

The original simulation showed a maximum von mises stress of 335.2 MPA, which would be over the limit of the Q235 steel (235 MPA). With the feet lengthened to their maximum of 120 cm however, the stress on the beams reached a maximum of 132.6 MPA. This means that, with the feet lengthened to the maximum of 120 cm, the Z-box can be loaded to its maximum capacity. To figure out if widening the 3.5 m driveway is possible, different lengths were tested. These results can be seen in Figure 51.

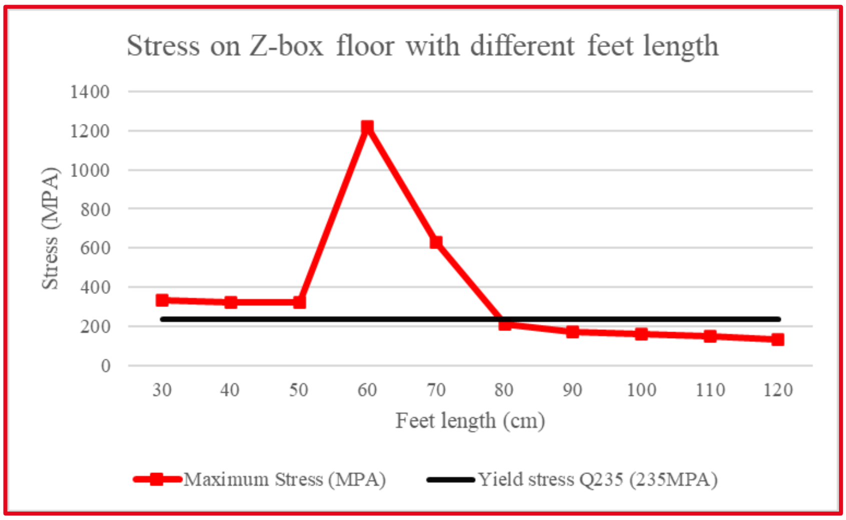


Figure 51 Floor stresses with different lengths of feet

It should be noted that the values for 70 cm and 60 cm feet are enough of an outlier to be considered an error. However, these cannot be simply dismissed without proper reasoning. Therefore, a look is taken at the interquartile range [28], which can show us whether or not these data points can statistically be defined as outliers. Outliers would be defined as being below $Q1 - 1.5\,IQR$ or above $Q3 + 1.5\,IQR$ [29]. $Q1$ is the median of the lower half of data points, which is 158.8. $Q3$ is defined as the median of the second half of data points, which is 329.7. The IQR can be calculated by subtracting Q1 from Q3. This would put the IQR at 170. The cut-off for the upper outliers then is $329.7 + 1.5 * 170 = 585.9$. Seeing as the two data points are 1218 and 627 respectively, they can be considered outliers and thus have no bearing on the rest of the data. A likely explanation could be an anomaly in the simulation SolidWorks performed. Regardless, feet of at least 80 cm are needed, which puts the driveway at a length of approximately 4.2 meters.

The main thing to conclude from this (sub)section is that the stress on the overhanging Model 2 floor is not necessarily the limiting factor for the weight limit anymore.

Effect on the roof

A second analysis will also be done on the roof of the lower Z-box, with the lengthened feet of the upper Z-box spreading the load. This should help bring the maximum carrying capacity of the frame to the 11800 kg reached in the structural report. In the original simulation, (feet having a length of 30 cm), the maximum bending stress is 783MPA. To figure out if lengthening the feet is enough of an improvement, the first simulation is done with a length of 120 cm. After all, if the roof is not structurally capable of carrying the maximum load with the feet lengthened to the maximum, shortening it would only decrease the carrying capacity.

When the feet are lengthened to 120 cm, this maximum von Mises stress reduces to 249 MPA. While this is a significant improvement, it is still over the limit of the Q235 steel. This means that with the driveway set to 3.5 m, the maximum capacity of the overhanging model 2 Z-boxes can still not be reached. That once again leaves two options, either lowering the maximum weight, or somehow redesigning the floor. To figure out if the penalty of lowering the weight is worth it, several more simulations are performed.

As can be seen in Figure 52, the maximum weight that the roof of the lower Z-box is able to safely carry inside the upper Z-box is around 4100 kg. This is a reduction of 10%, which can be justified with the need for a discount that came forward in the market research.

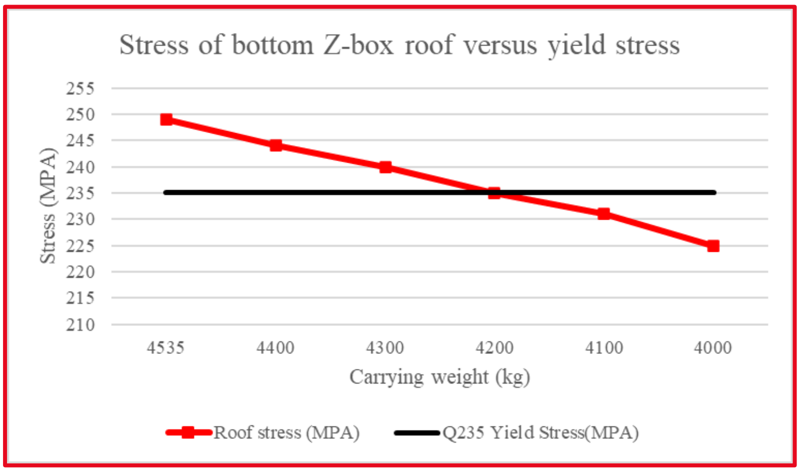


Figure 52 Stresses on the Z-box roof with 120 cm feet

6.1.3 Model 5

While lengthening the feet so more force is divided over the frame helps for the overhanging model 2, the same also needs to be tested for the model 5's lining the edges of the storage park. Here, lengthening the feet parallel to the walls, would only cause more force to be moved to the sheet metal top of the Z-box (at least on the inner edge). The lessons that were learned earlier could also be applied here though. First of all, the lengthwise walls of the Z-box are able to carry the majority of the force pushing down on it. Therefore, this force needs to be transferred from the sheet metal to the lengthwise frame. In order to achieve that, the feet of the model 5 can be moved, so that they rest on the lower lengthwise frame. The comparison between the two can be seen in Figure 53.

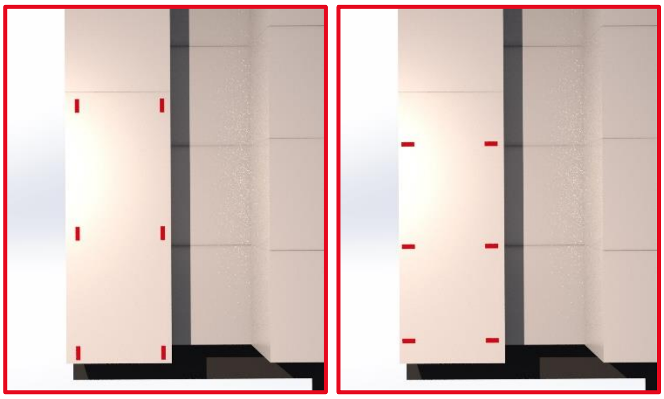


Figure 53 Comparison between the old (left) feet layout and the new (right) feet layout

The situation presented does not require a full new set of simulations to be ran. This is because of the fact that with the feet rotated, the Model 5 will exert the same types of forces as the Model 2. The weight of a Model 5 pushing down onto the frame of the Model 2 is $\frac{1835\ kg + 4535\ kg}{2} = 3235kg$, so a 142 kg weight increase on the $3092.5kg$ of a fully loaded Model 2. This means that the capacity of the Model 5 should decrease by 142 kg compared to the 4100 kg of the Model 2, bringing the capacity down to approximately 3950 kg.

6.1.4 Summary

The following takeaways can be brought forward:

- The driveway should be 3.5 m wide, giving the roof of the lower Model 2 the maximum amount of overlap with the floor of the overhanging Model 2, which spreads the load
- The overhanging Model 2 should have a weight limit set at 4100 kg.
- The Model 5 resting at the edges of the storage park should have a weight limit set at 3950 kg.
- The feet of the Model 5 should be rotated and moved so that they are supported in line with the edge of the lower Model 2.

6.2 Joining the Z-boxes

As mentioned during the key considerations, it was proposed that in order to increase the chances of a successful permit inspection, it would be beneficial to add another safety device. The main driver was that both the Model 2's hanging over the driveway as well as the Model 5's along the edges were now all standing separately next to each other. While the structural report [9] determined that wind would not be an issue, adding another redundancy increases not only the chances of a successful permit inspection, but also the perceived safety.

Originally, the client also asked for the Z-boxes to be attached to the ground below. This was deemed of little added value however, since the proposed solutions will already prevent the structure from falling over. An entire chapter for this design was therefore deemed unnecessary. A few options are shown in Appendix E.1.

The following key considerations will be utilized in this section:

- *The construction methods should focus on minimizing the construction time.*
- *The Z-box cannot be altered in any way that would prevent them from returning to their original state.*
- *The construction methods should focus on minimizing the amount of material.*
- *The Z-boxes should be attached to one another.*
- *The structure should be able to withstand external forces, such as wind, snow, rain.*

In an effort to find a proper starting point for the design, TRIZ can be applied.

6.2.1 TRIZ

TRIZ is an innovation method that originated in Russia. Its name, TRIZ, is a Russian acronym meaning the theory of inventive problem solving [30]. The basis of this method was research by Russian military patent examiner Genrich Altshuller, who studied over 400,000 patents to understand how inventors came up with solutions to design problems. Over the years this method has been developed and refined, eventually becoming a comprehensive method to solve problems in product development.

TRIZ includes different methods and techniques that can be used in several stages of the idea generation process. These include ways to generate ideas and solve problems, evaluating the ideas by ranking them, or looking at specific technology trends to explore new ideas.

The TRIZ method that seems to be of most use in the specific case of attaching the upper row of Z-boxes together is the one of *inventive problem solving*. In this method, a contradiction is described, which is then used to cross-reference the corresponding inventive principles in a contradiction matrix.

The Z-boxes need to be attached to both each other and to the lower Z-boxes. The positive section used for the contradiction matrix is that this would make the structure sturdier by increasing its total weight. Describing this as a positive TRIZ term would be the 'weight of the stationary'. The negative part here would be the increase in cost/materials. In TRIZ, the negative section would then be the quantity of substance. Cross-referencing these in the contradiction matrix gives us the following principles:

- Periodic action
- Universality
- Mechanical vibration
- Copying

The one that was deemed to be of most use was the Universality principle. Here, the main idea is to eliminate the need for total parts by making parts or objects fulfil multiple functions. In the case of improving the total weight of the structure, the outer upper Z-boxes can act as the attachment to the lower row of Z-boxes, with the ones in between being only attached to each other. The universality principle is then applied to the outer brackets in the way that they not only attach the two outer Z-boxes to the ground floor, but in a way all of the middle Z-boxes as well. That leaves two things to be designed:

- A system that attaches the top layer Z-boxes to each neighbouring Z-box.
- A system that attaches the outer two Z-boxes to the lower Z-boxes.

6.2.2 Bracket L-L

In the process of researching current solutions for shipping containers, several options came up. The most promising of these option was the bridge fitting clamp, as shown in Figure 54.

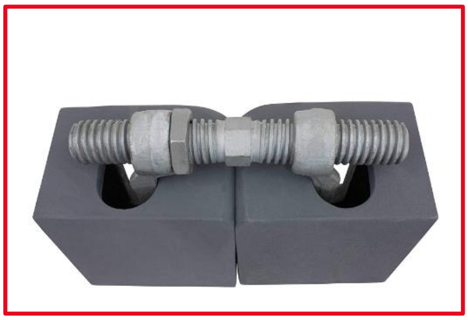


Figure 54 Bridge fitting clamp. Retrieved from: myteeproducts.com

Buying these bridge fitting clamps cost around $45, which would have to be a significant expense in total. On top of that, the bridge fitting clamp is designed to withstand the forces of the sea during shipping for fully filled containers, which would be a lot higher than the case would be for the Z-boxes. This design could however be used as an inspiration for the design of the bracket.

Clamping or joining the Z-boxes together can be done in a few general locations. These locations can be seen in Figure 55, with Figure 56 detailing them. Location 2 and 3 allow for a solution that functions similar to the bridge fitting clamps, while Location 1 requires another solution.

Figure 55 Different joining locations

Location 1: Non-door side of the corner

Location 2: Crosswise side of the bottom structure

Location 3: Lengthwise side of the bottom corner structure

Figure 56 Different clamping location options

Location 1 – U-Bracket

The first concept makes use of the bolts already present at the side of the corner facing away from the door. This means that it could be used in both the Model 2's as well as the Model 5's. The bolts can simply be attached to each other by making use of a u-bracket that connects both of them together. One can loosen both screws, and then tighten them again with the bracket in between. This can be seen in Figure 57

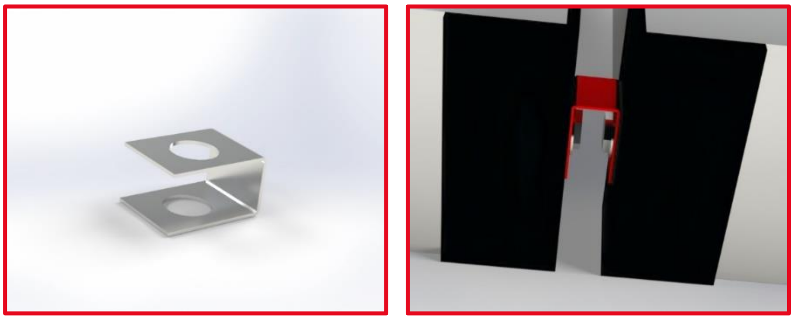


Figure 57 Option 1: U-bracket

Location 2 – Bridge fitting clamp

As mentioned earlier, the bridge fittings that are currently available are expensive to buy solely for the purpose of clamping the Z-boxes together. This is partly due to the fact that they would be overengineered for the specific purpose in this project. Therefore, a simpler design is put forward that could aid in this problem. It makes use of the extrusions located on the crosswise side of the bottom.

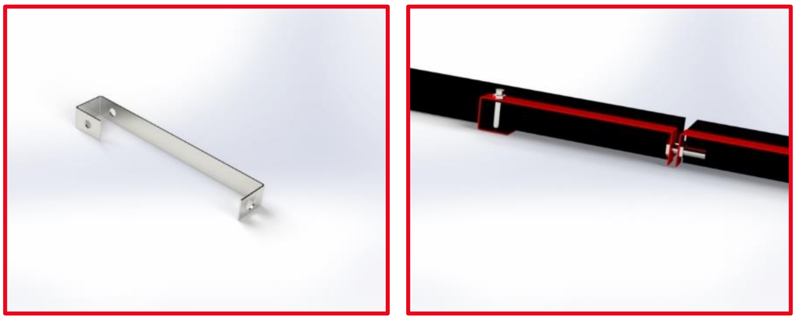


Figure 58 Concept 2: Bridge fitting clamp

Location 3 - Bridge fitting clamp variation

Location 3 once again lends itself to a bridge fitting variation. A variation of the bridge fitting clamp of location 2 might be applicable here, where the middle screw is rotated. This can be seen in Figure 59.

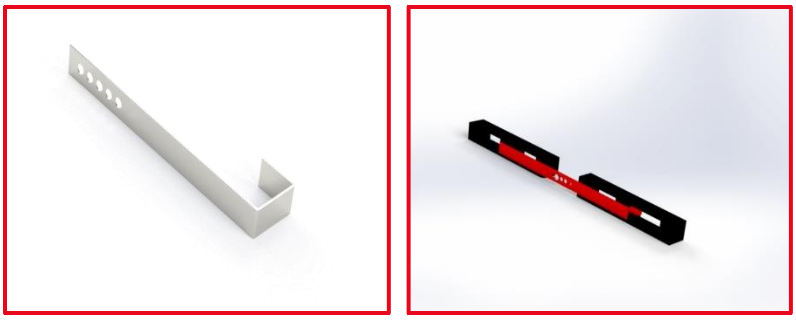


Figure 59 Concept 3: Bridge fitting clamp variation

Rating the concepts

There are a few things to consider determining the best path forward. The U-bracket for location 1 has an excellent minimalist use of material, due to the close proximity of the mounting points. On top of that, it can be installed on both the Model 2's, and the Model 5's, as the mounting screws will always be facing each other. The main downside is the fact that in its current state, the bracket is not able handle differences in distance between the Z-boxes.

This is for instance not the case in the bridge fitting clamp for location 2, where the distance between two Z-boxes is only limited by the maximum length of the threaded screw or rod. The main downside here is the fact that the mounting point is only located at the front of the crosswise side, meaning that they can only be used when joining the Model 2's together.

For the Model 5's, the variation on the bridge fitting clamp for location 3 would be a good fit. It has the same benefits of the original bridge fitting clamp where the distance between the Z-boxes does not matter as much. Initially, it might seem that this would then not work on the overhanging Model 2's, but there is a mounting location present under the floor. This location can be seen in Figure 60. While this mounting orientation on this hole might be different then the original one depicted in the image of location 3, it will still work in the same manner and therefore needs no adaptation on that front.

Figure 60 Mounting location on underside model 2

Initially, after these considerations both the U-bracket, and the variation on the bridge fitting clamp were brought forward. During further iteration however, the U-bracket showed unfeasible due to the large amount of material that had to be removed in order to make it more modular to account for the distances between the Z-box. Therefore, the decision was made to only move forward with the bridge fitting clamp variation of location 3, hereafter named Bracket L-L. The iteration on the U-bracket can still be found in Appendix E.2. Figure 61 shows Bracket L-L being attached to two the two different mounting points.

Figure 61 Bracket L-L at its two designated mounting points

Prototyping

A 3D printer was used to print the initial Solidworks model, 1:1 scale, to test it at the storage park in Deventer. Several iterations proved to be necessary, before landing on the final design. One of the noteworthy changes was changing the thickness from .8 mm to 3 mm steel, as this was steel that was readily available at the company already. These iterations can be seen in Figure 62.

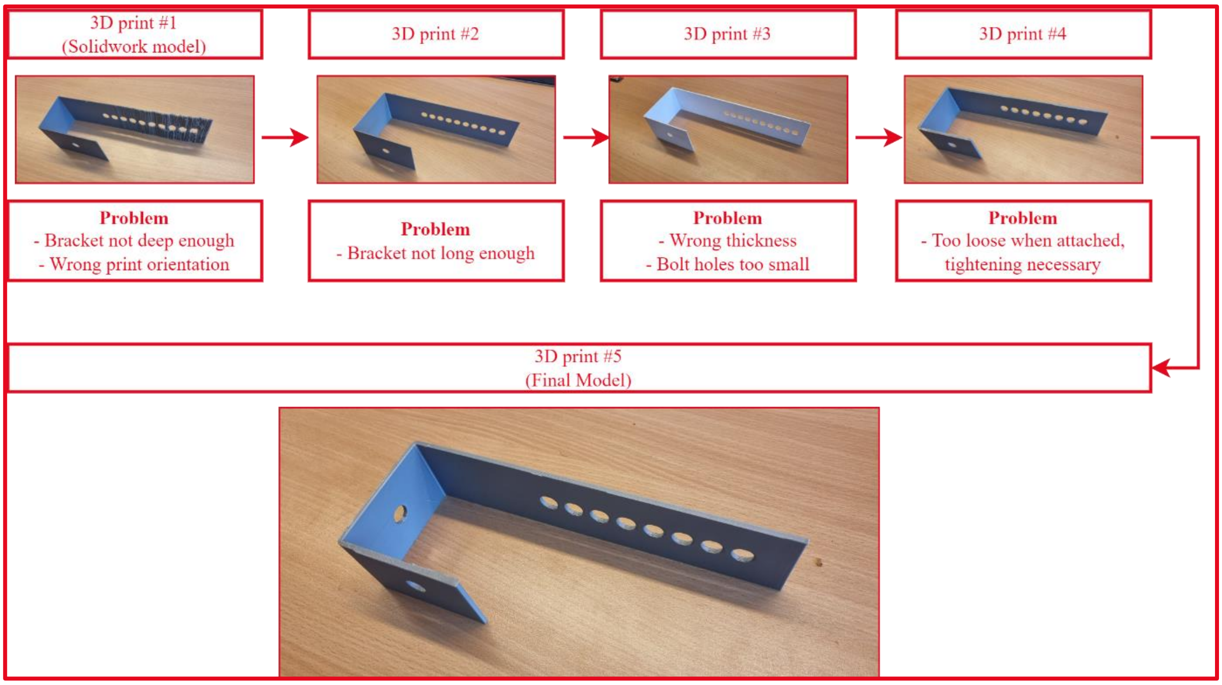


Figure 62 Iteration progression

Strength

The L-L bracket has also been simulated in order to test its strength (see Appendix E.3). With a delivery van crashing into the Z-box at 15 km/h, the bracket will fail. However, this bracket is currently simulated to be holding the last Model 2 in the driveway being hit from inside the tunnel. This begs the question as to how the vehicle even managed to get in the tunnel if it is high enough to crash into the top Z-box. On top of that, the outermost Z-box will also be connected to the lower level making it a lot stronger. If a simulation was done on a more realistic simulation (i.e., a car hitting the structure while trying to get into the tunnel) the weight of the Z-boxes behind it needs to be taken into consideration as well. This means that the structure is a lot harder to push. Not just because of the friction of the last Z-box, but also due to the brackets holding it to the lower layer. The force that the friction pushes back as is calculated with $F_{max} = \mu * mg$. If the structure needed to withstand the scenario with a force of 88kn, it needs to weigh approximately 18000 kilos ($0.50 * 18000kg * 9.81 = 88kn$).This is equal to around 11 empty Z-boxes, or 5 half-filled Z-boxes.

With that weight behind it, the structure will hold this collision, even without the brackets attaching it to the lower level. The brackets therefore serve more as a fail-safe when a vehicle scrapes the floor of the top Z-boxes while riding in the tunnel.

Final model

In order to move on from a 3D printed bracket to a final model, instructions on how to make the brackets were created for the freelancer. The most important part were the technical drawings, which can be found in Appendix F.1. After the first two brackets were created they were placed onto the Z-box in the manner that they were designed for. As can be seen in Figure 63, they fit exactly as intended. Due to the layout of the current testing being done at the park, the location under the Model 2's could unfortunately not be tested. It did become clear that the 3D printed prototypes played a large part in this successful creation thus far. In the future, these brackets will be painted red as this was a request of the client, and it matches the brand colours.

Figure 63 Final model of bracket

When more of these brackets are placed, it could be that a lot of the centre holes continuously remain unused. In that case, they can be removed from future brackets. Yet, due to the margins of error when placing the Z-boxes, this would not immediately be advisable. The cost calculations showed that the bracket will cost around €46 euro per set. These calculations can be found in Appendix E.4.

6.2.3 Bracket 2-2

The second safety device is mounting the upper Z-boxes to the lower layer of Z-boxes. This aids once again in connecting more Z-boxes together, and thus, increases the force needed to move the structure. As these brackets will only be located on either end of the structure, the need for minimizing complexity and material use is loosened somewhat.

Mounting location

The overhanging Model 2's are deemed to be of most importance due to the possibility of a vehicle driving into it. The strongest and thus most viable mounting location for the Model 2's is the floor. This is due to the fact that a bracket here can be designed to fully clamp around it, instead of relying on for instance the bolts at the corner. The decision to move away from the steel strips was also necessary. The better choice here would be steel beams, as those are (relatively) cheap, and provide a much larger structural benefit. Lastly, the issue that arises here is the fact that the only thing in line with the floor of the overhanging Model 2 is the at the door side of the lower Model 2

Therefore, the decision was made to mount the lower side of the bracket in between the first and second Z -Boxes in a row as shown in Figure 64. Now, any significant amount of force from either the front or back will cause the brackets to transfer the loads to the corners of the Z-box, which will provide a lot higher structural integrity than any brackets.

Figure 64 Mounting location of bracket 2-2

A rough model was made as a starting point as shown in Figure 65.

Here, three main issues came to light. The first one is the fact that the beam uses an unnecessary amount of material in order to reach the centre of the Z-box. On top of that, the length of the beam would cause an unnecessary amount of moment/force on the welded corners, something that is undesirable. Lastly, the driveway height would be reduced again.

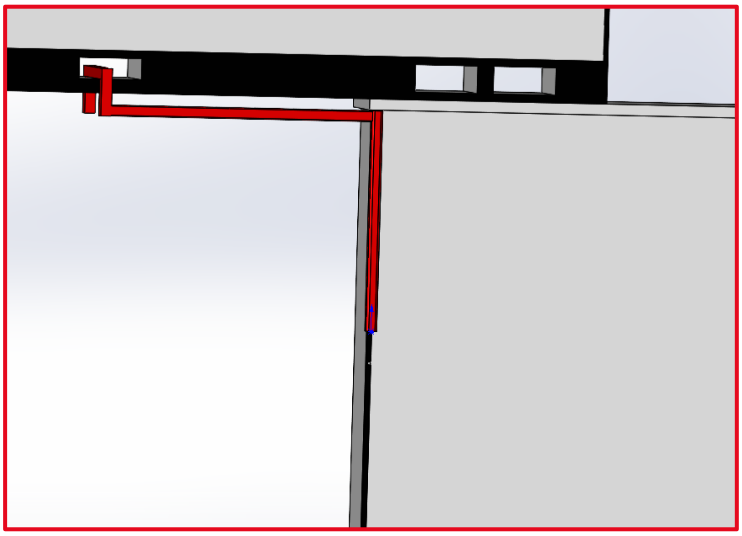


Figure 65 Initial model of attachment bracket model 2-2|

These observations resulted in the decision to move the floor mounting location to the side holes, which are significantly closer than the middle ones. This can be seen in Figure 66.

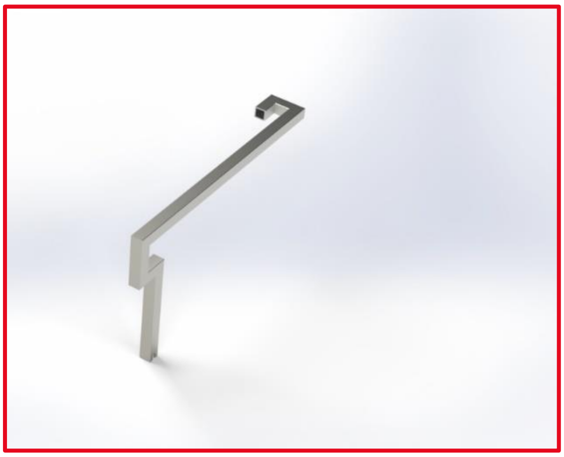


Figure 66 Second iteration bracket 2-2

Attachment method

As explained earlier, the bracket will be resting in between the two lower Z-boxes and be held in place by the bolts on the corner structure. This part of the bracket has no structural need other than to transfer the force to the lower Z-box. Therefore, the length is shortened to only reach the top bolt in the corner. A small slot is cut into the bottom to account for the sleight height differences of the two Z-boxes. This can be seen in the transparent render in Figure 67.

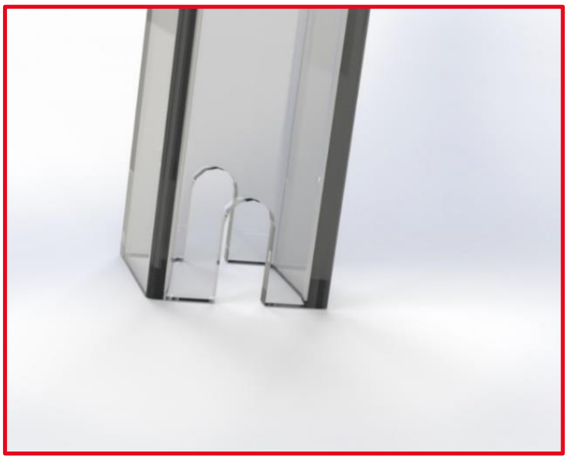


Figure 67 Attachment slot bracket 2-2

Tube size

As these tubular sections can be bought precut, a seller is chosen [31] . This retailer (Staalvakman) sells different prefabs that could be used here. As the Solidworks model was created using a technique called 'weldments' a lot of different tubes could be tested in succession. The first restriction here is the width in between the lower Z-boxes. In the desirable case that the Z-boxes are pushed tightly together, the gap in between them measures 45 mm in width. This gives us our maximum steel width of 40 mm. The choice was made to go with a square tube shape as opposed to a rectangular one, as there are no discernible downsides to it. At the same time, the maximum steel thickness is chosen, which was 4 mm.

Simulation

Lastly, as an initial test, a load simulation was done on the bracket, using the same forces from the simulations on Bracket L-L (= 44 kN per bracket). This would then simulate a Ford transit trying to enter the tunnel at 15 km/h, before crashing into the first overhanging Model 2. If it were the only Z-box in the row, the simulations indicated that the bracket would fail. As this Z-box is not intended to be on its own however, this is of no concern. After all, the Z-boxes placed behind it would still be able to hold this force, especially if this bracket takes the brunt of it. In the situation where someone would want to place only one Z-box, 4 brackets would be needed to attach it to either side, changing the force to ‘only’ 22 kN per bracket. In that case, the simulation shows the bracket would be sufficient, as can be seen in Figure 68.

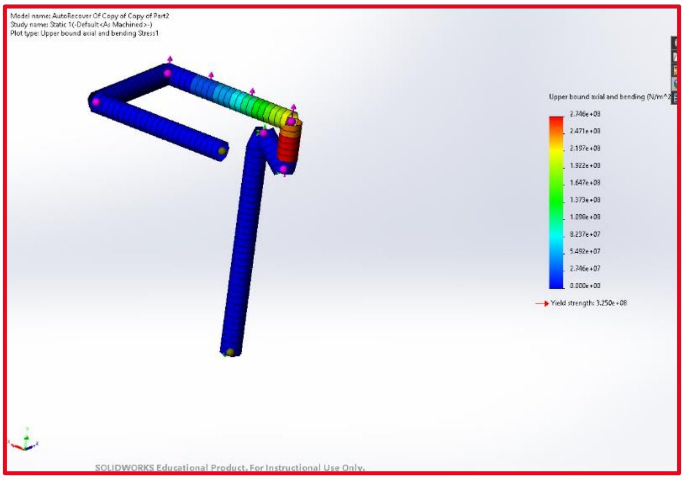


Figure 68 22 kN load simulation bracket 2-2

Prototyping

In order to determine the exact sizes & tolerances needed, the 3D printer was used once again. The approach to this prototyping phase was determined by the different steel sections that needed to be welded together. This not only allowed for a close approximation of the sizes needed, but also helped determine the tube lengths that need to be ordered. To speed up the iteration process, the different sections here split up to be printed separately. This allowed for small size changes without having to alter the entire bracket. The most important section was the part of the bracket that needs to move around the roof. Luckily, the 3D printed part showed that the measurements taken during the design process were correct. Similar to bracket L-L, the current park layout unfortunately did not allow a full test of the bracket hooking into the floor of the overhanging Model 2.

Figure 69 3D printed version of bracket 2-2

Final model

Once again, instructions on creating this bracket were send to the freelancer to build the final model (Appendix F.2). These brackets should also be painted red in the future. While the measurement of the steel section that will need to go around the roof have been confirmed by the 3D printed model, the section that hooks around the floor of the overhanging model 2 could still not be tested in the current park layout. This final model did proof fruitful for determining the cost of 1 of these brackets, which was around €93. This calculation can be found in appendix E.5.

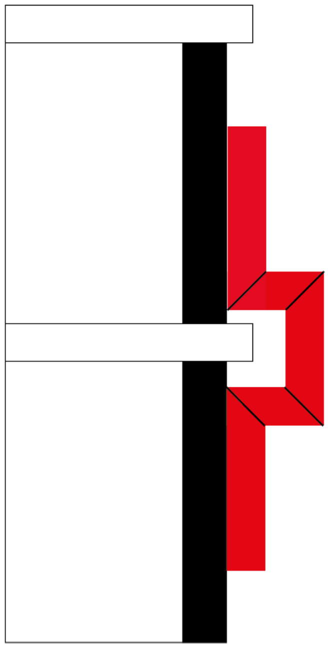
Figure 70 Final model of bracket 2-2

6.2.4 Bracket 5-2

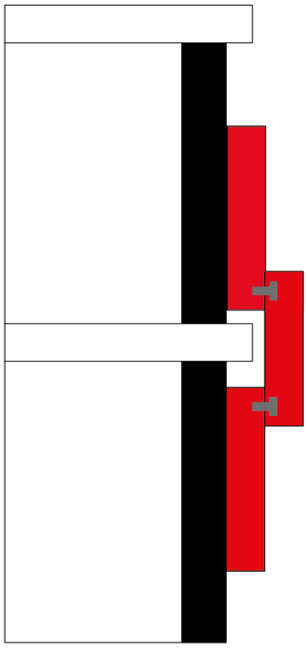
While the Model 5 will likely not be subjected to the same forces as the Model 2, it still needs a solid, structurally sound attachment to the lower level. The location of this bracket would be at its best at the bolts on the side of the model 5.

Concept

The bolts on the corner of the upper Model 5 line up with the Model 2 at the bottom. The only thing in the way would be the roof. Getting around it can either be done in the same (welded) manner as bracket 2-2, or in a cheaper way. Both of these options are shown below:



Option 1: Dividing the bracket up into seperate welded sections



Option 2: Dividing the bracket up into seperate sections bolted together

Here, option 2 is cheaper due to the decreased amount of manual labour it requires. The strength that the welded bracket provides is not really necessary, as there will not be a shear force acting on the bracket. Due to the simplicity of this concept, the choice was made to not iterate on it. The only things to consider is the distance from the top bolt to the roof, the overhang of the roof, and the distance from the floor to the bottom bolt of the top one.

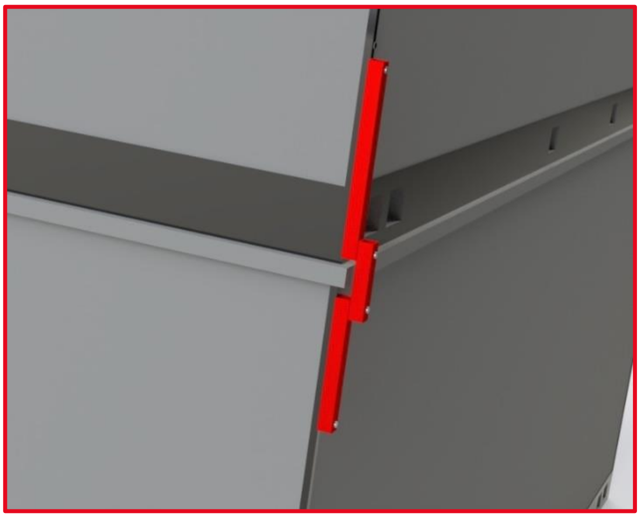


Figure 71 Render of model 5 bracket

Due to the short length of the roof overhang, a smaller size tube can be used, that is also marginally cheaper. However, after further consideration, the choice was made to stick with the same 40 mm x 40 mm x 4 mm tube steel. This is due to ease of ordering & organizing, and so that any scrap pieces of tube that won't fit bracket 2-2 can be used in this configuration.

Final Model

As the design for this bracket is far less complicated when compared to the previous 2, the decision was made to forego a 3D printed model. Instead, the exact sizing was cut out of carboard to confirm the measurements taken earlier. These measurements were used to create a final technical drawing of the bracket, which was sent to the freelancer, who created the model. This can be seen Appendix F.3.

One important thing to note here is that the holes connecting the middle bracket to the outer two were not drilled initially. This decision was made after a test install saw the holes not line up completely, due to small differences in the heights. After more of these brackets are build, an average location with a sufficiently small margin of error could maybe be found. Yet, the actual benefits drilling the holes beforehand would provide are likely too small to consider. Once again, the bracket will be painted red in the future.

Table 7 Final model of bracket 5-2

Cost

The total amount of tube needed is 105 cm. With the aforementioned cost-saving established by letting the tubes be cut by the freelancer, the same approach is taken here. A tube of 4 meter would give too little margin to create 4 brackets. Yet, the remaining material can be used to create bracket 2-2 and thus ordering a 4-meter tube is still viable. Cutting 3 times, with the drilling of 5 holes, took around 20 minutes. This brings the total cost to €8.33 + €16.64 = €24.97, rounded off being €25.

6.3 Experience compass implementation

Now that the functional design for the brackets has been finalized, a look is taken at the peripherals that the customers will have a direct connection with such as the stairs, bridges, and railings. While these off-the-shelf peripherals are in its essence purely functional, certain adaptations can still be made to improve the overall user experience and their comfortableness utilizing the park. The key considerations will be taken into account in this section:

- *Customers should not be deterred from using the park due to safety concerns.*
- *The railings closing off open areas should have a height of at least 1 meter.*
- *The gaps in the railings closing off open areas should not exceed 0.5 meters.*
- *The stairs should not exceed a width of 1 meter.*
- *Peripherals such as stairs and bridges should be bought off-the-shelf.*

For this, the Experience Compass as created in chapter 4 can be used. Dividing the optimal location as indicated by the client in section 4.3 into the two main axes will result in the optimal positions that can be seen in Figure 72.

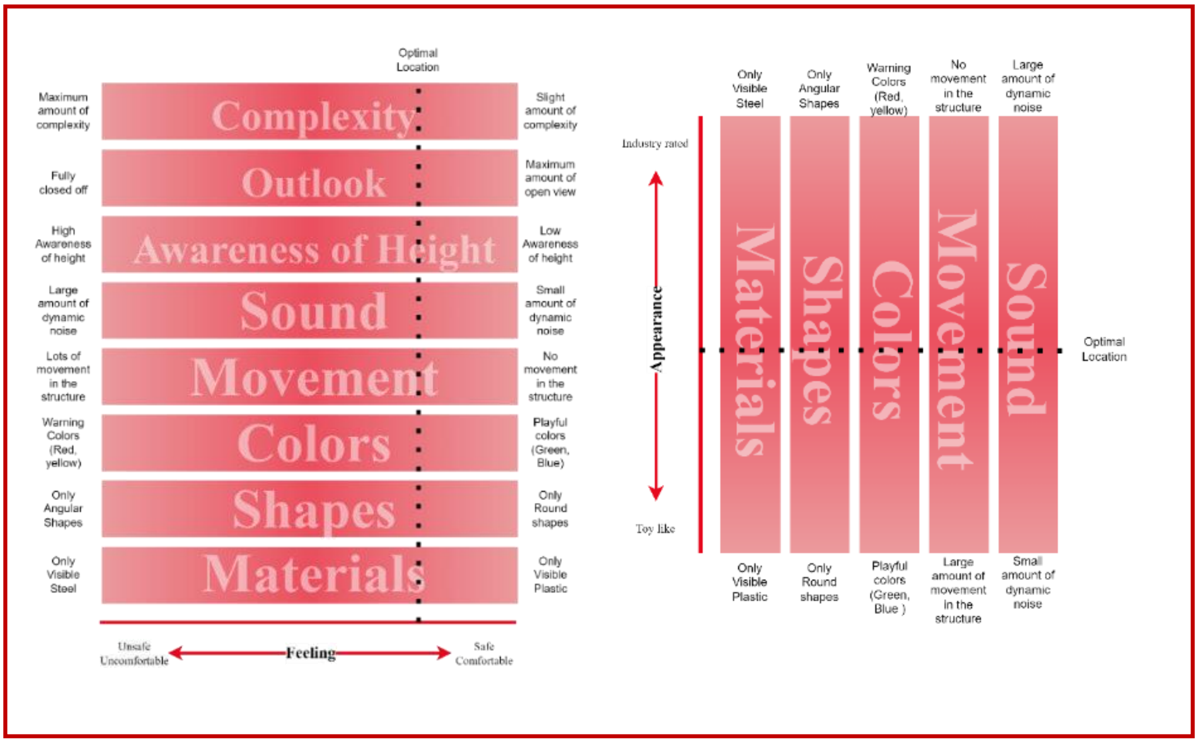


Figure 72 Optimal location divided over the two axes of the experience compass

A few adaptations will be made to make the experience compass more suitable for this two-story storage park. First of all, the ‘playful’ colours (blue, green) as placed at the far end of the feeling and appearance axis will be altered to more neutral colours (black & white). This will likely have a negative impact on the effectivity of the experience compass but will make sure that the adaptations made by the experience compass will not visually clash with the existing structures such as the Z-boxes.

Another change that has to be done before the experience compass can be utilized effectively is combining the optimal locations. As both of these axes contain a number of similar aspects, they can be combined to determine the average optimal of each of the separate blocks. It should be noted that optimal location on “Complexity”, “Outlook”, and “Awareness of Height” will not differ from the optimal location as determined on the feeling axis. After all, they do not appear on the appearance axis and are thus not influenced by this. On top of that, the “movement” block is flipped around on the appearance axis (as a lot of movement does not inspire safety but does indicate a toy-like structure). Thus, this should be accounted for as well. These changes result in the graph as can be seen in Figure 73.

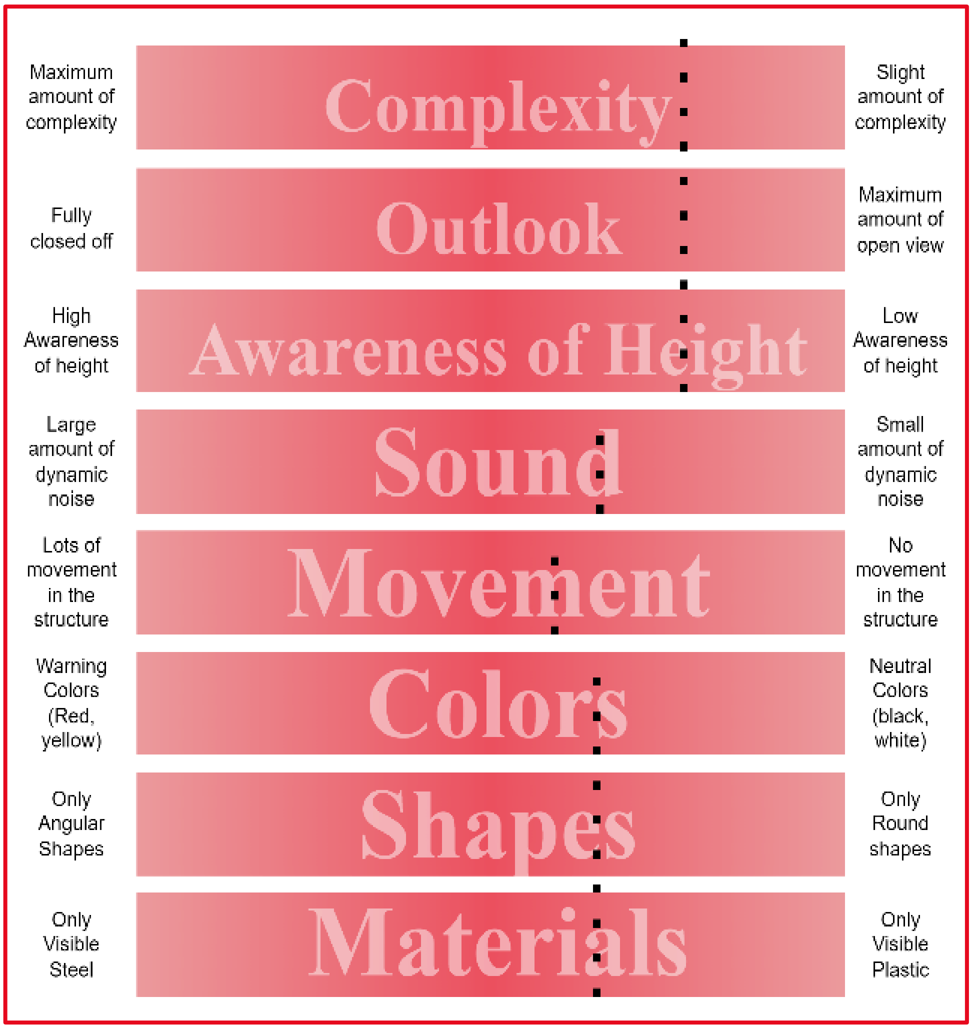


Figure 73 Combined optimal locations

These design adaptations as inspired by the experience compass will be implemented on the off-the shelf components of the park. While their functionality has been established, certain design changes can easily be implemented.

6.3.1 Stairs

In order to gauge the different changes that could be made to the stairs, a rough 3D model was created. This will allow a way to quickly check different configurations. This 3D model and the comparison to its real-life counterpart [10] can be seen in Figure 74.

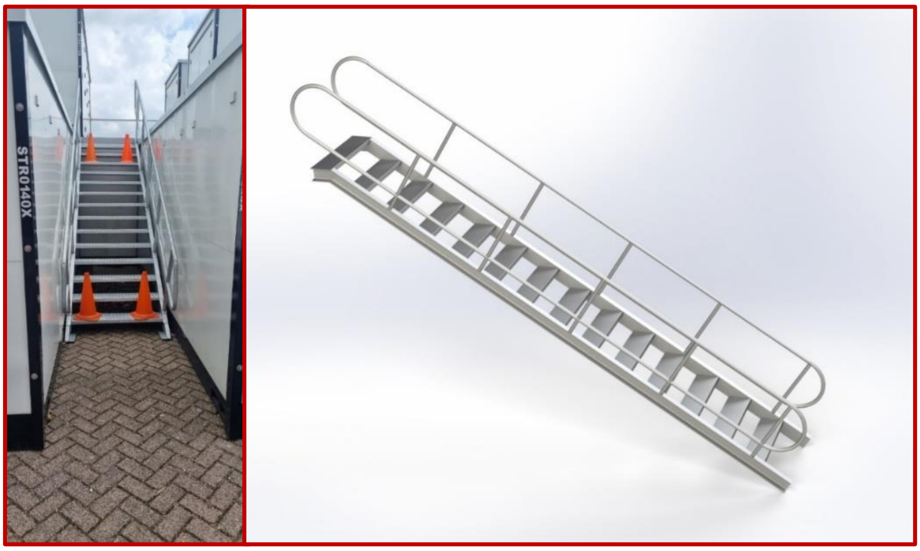


Figure 74 Comparison between real-life stairs and its (rough) CAD model

To bring the stairs closer towards the ideal location on the compass, some of the (relevant) blocks can be looked at separately. The experience compass is set up in a way where not every block has to be used. For instance, the two Model 5's flanking the Z-box already give the stairs minimal outlook, with no way to change it. The decision was therefore made to not alter anything about the stairs in that instance. Another thing to note is that the stairs are not looked at in isolation fully. Considering the stairs in isolation for the sound, every step should be covered in rubber panels to dampen the dynamic sound. Yet, the entire walkway of the two-story storage park will already have been covered in rubber panels meaning that extra alterations to the stairs are not needed.

One design alteration to the stairs that is not connected to the experience compass is a way to prevent peoples belongings from dropping into the gaps between the steps. This can be accomplished simply by using a plate of wood. The plank will be painted white, as it is a neutral colour that matches the Z-boxes but also aligns with the experience compass.

	Current situation	**Adaptation according to experience compass**
Complexity	Low	-
Outlook	Closed off	-
Awareness of Height	Low	-
Sound	Low	-
Movement	Minor	Extra clamping to Model 2 Z-box
Colours	Grey (Stainless steel)	Adding black sections White plank
Shapes	Combination of round and square	-
Materials	Stainless steel	Covering parts with PVC

Table 8 Stair alterations according to the experience compass

Implementing these changes would cause the stairs to look as shown in Figure 75.

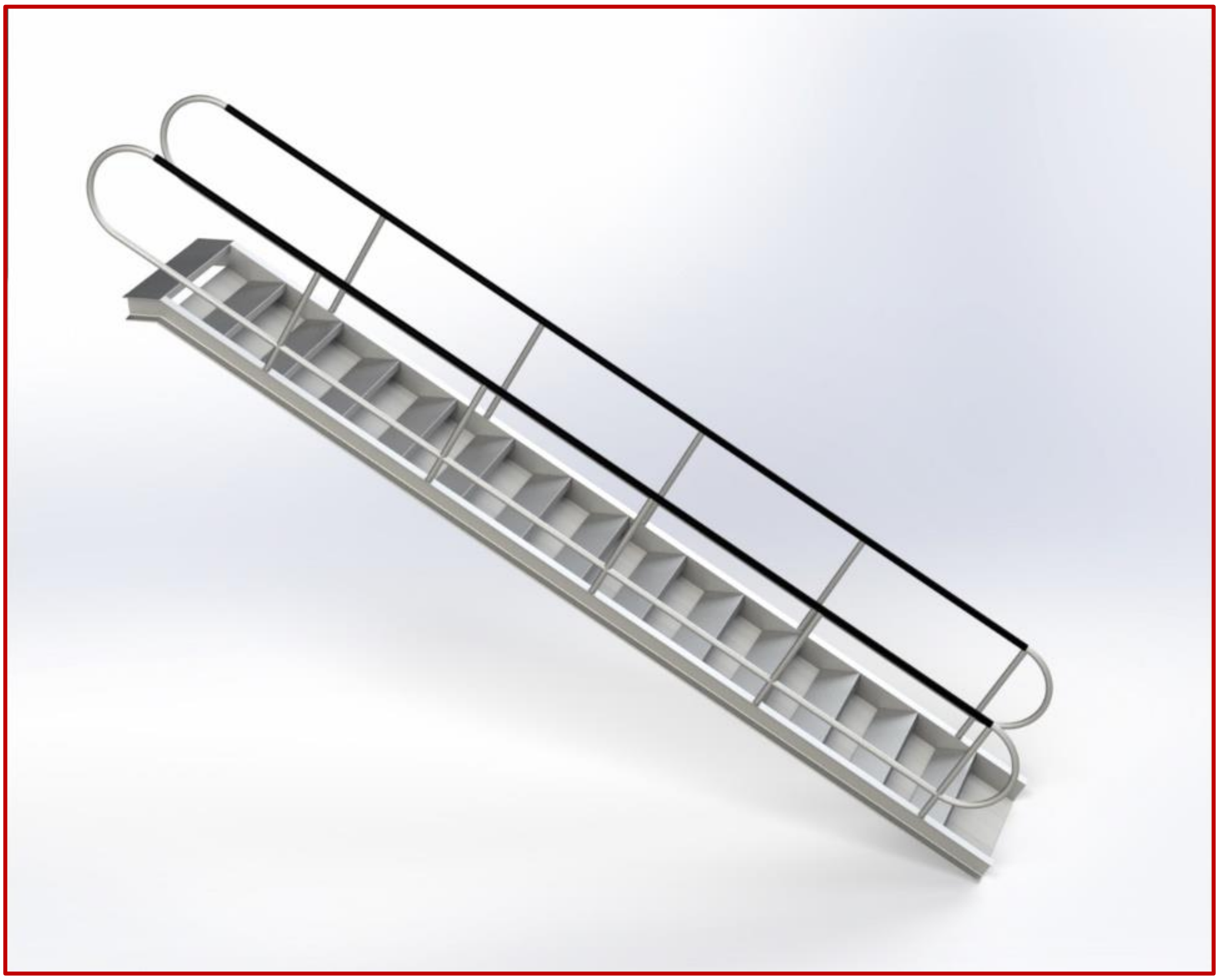


Figure 75 Stairs with the adaptations inspired by the experience compass

While the changes might seem minor, it is worth noting that the adaptations made to these stairs will simply aid the outlook and feeling of the entire storage park to change. An evaluation will have to be performed to validate the effectivity of the experience compass. If the above changes have not shifted the location on the experience compass enough, one could go back and change more things.

6.3.2 Bridges

The bridge installed at the storage park in Deventer has worked perfectly so far, providing a good balance between cost and usability. However, the bridge is currently flanked by two Z-boxes acting as walls. This works well in this configuration, but the simulations showed that the Model 2 Z-boxes need to be lined up on top of each other. This would create a gap for the bridge that has the width of one Z-box (2.42 m). Thus, the Z-boxes can't act as railings on both sides. Luckily, the company that placed the bridge (which is the same as the one for the stairs [10]) also sells bridges with a railing, rated for both 1.5 kN as well as 5 kN. To keep in line with the legislation for the walkways, the 5 kN bridge can be chosen. This one can be seen in Figure 76 [32]. The same figure also shows the 3D model that was build.

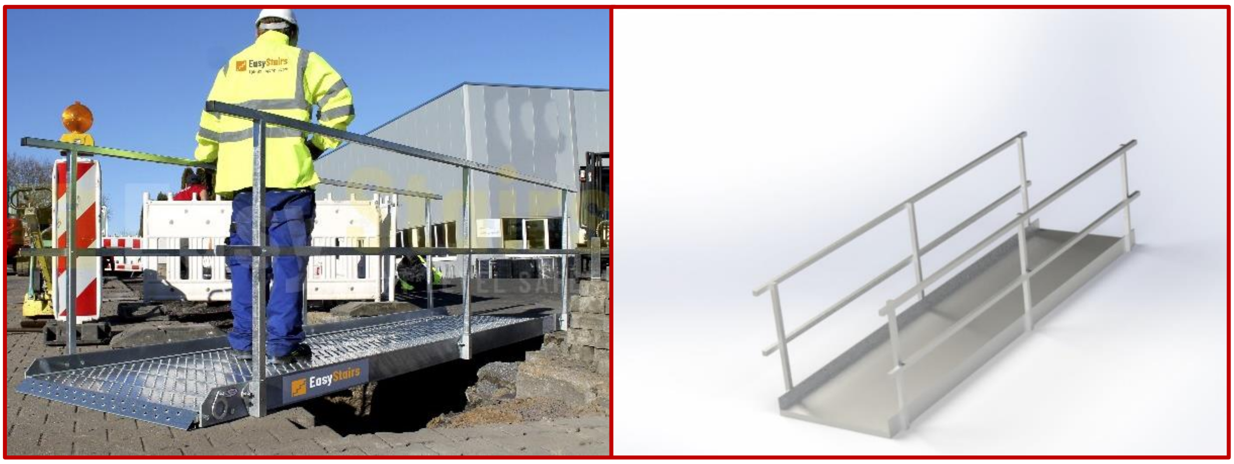


Figure 76 EasyStairs Bridge and its CAD counterpart

In the table below the adaptations that are needed according to the experience compass are described.

	Current situation	Adaptation according to experience compass
Complexity	Low	-
Outlook	Low	-
Awareness of height	Gaps	Covering the gaps with a billboard
Sound	Low	-
Movement	Minor movement	Bolting the bridge to the neighbouring Model 2 Z-box (Figure 78)
Colours	Grey (Stainless steel)	Making the material black
Shapes	Square	Rounding of the ends with (black) round caps
Materials	Stainless steel	Covering parts of the steel

Table 9 Adaptations for the bridge

Implementing these adaptations will result in the resulting bridge as shown in Figure 77. It is closed off on one side, keeping the steel visibility, awareness of height, and colour all in mind. The reasoning behind only covering one side is that the other side will be flanked by an overhanging Model 2. Figure 78 shows where the bridge can be bolted to the Model 2, preventing any lateral movement. While the current testing bridge installed in Deventer is bolted to a pair of beams that are resting inside of the forklift holes underneath, this same approach is not necessary for this bridge. This 4 m bridge is a singular part instead of the two-part bridge currently installed, with the ends already being supported by the Z-boxes themselves.

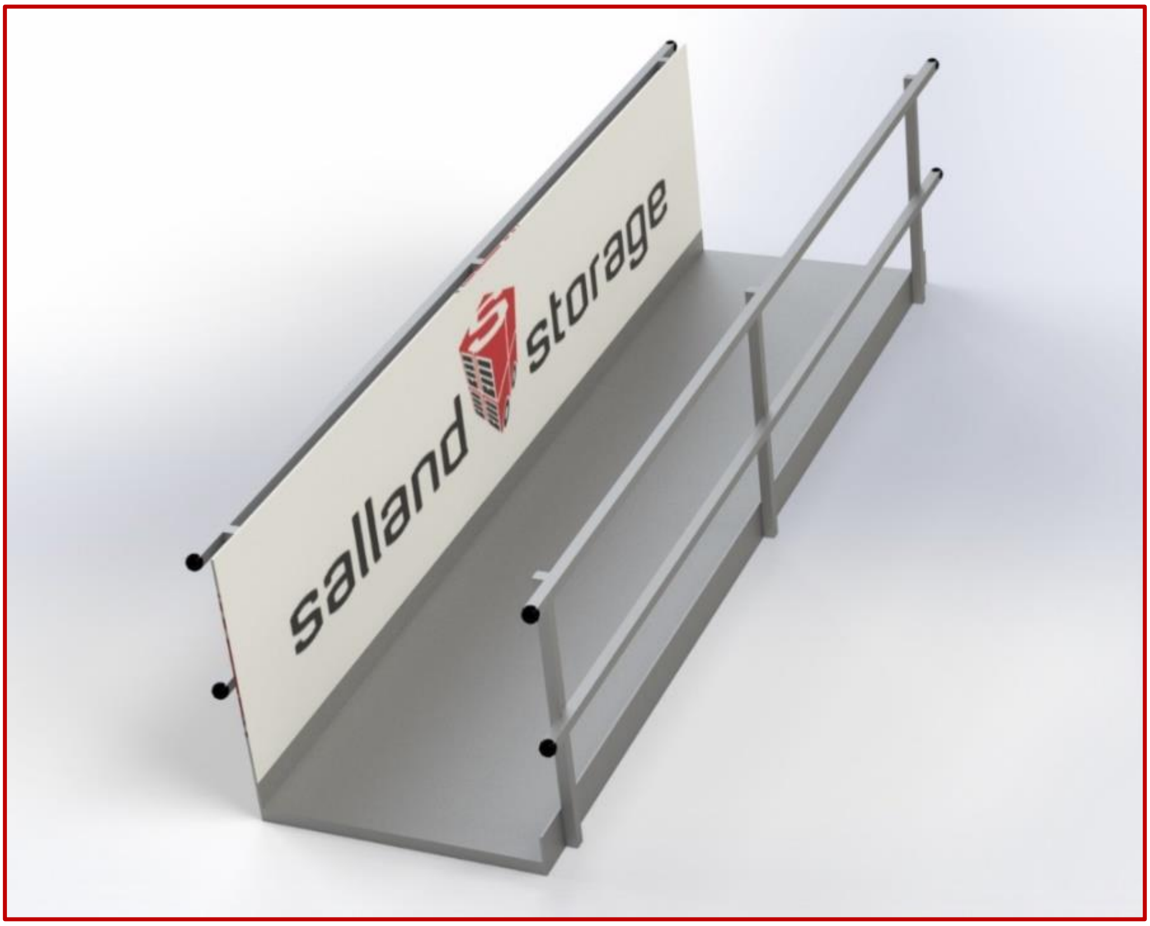


Figure 77 Bridge adaptation according to the experience compass

Figure 78 Mounting holes for the bridge

6.3.3 Railings

As with the stairs and bridge, a CAD model of the aluminium railing was constructed as well.

This design had been developed prior to the start of this thesis, specifically to accommodate for the difference in situations it would have to be placed. After all, before the performed research, the two-story storage park had a lot of different configurations where this railing could be needed. This is because not all of the Z-boxes were aligned exactly on top of each other, and thus its opposing neighbour. In the two-story storage park imagined in this thesis this is the case however, and thus a simple aluminium beam would suffice.

Figure 79 Railing installed in Deventer and its CAD counterpart

	Current situation	Adaptation according to experience compass
Complexity	Low	-
Outlook	High	Covering the lower half
Awareness of height	Full awareness	Covering the gaps with billboards
Sound	Low	-
Movement	Low	Bolting the railing to both the Z-boxes flanking it.
Colours	Grey (Stainless steel)	-
Shapes	Square	-
Materials	Stainless steel	-

Table 10 Adaptations to the railing

Implementing the changes of the experience compass will result in a railing as shown in Figure 80.

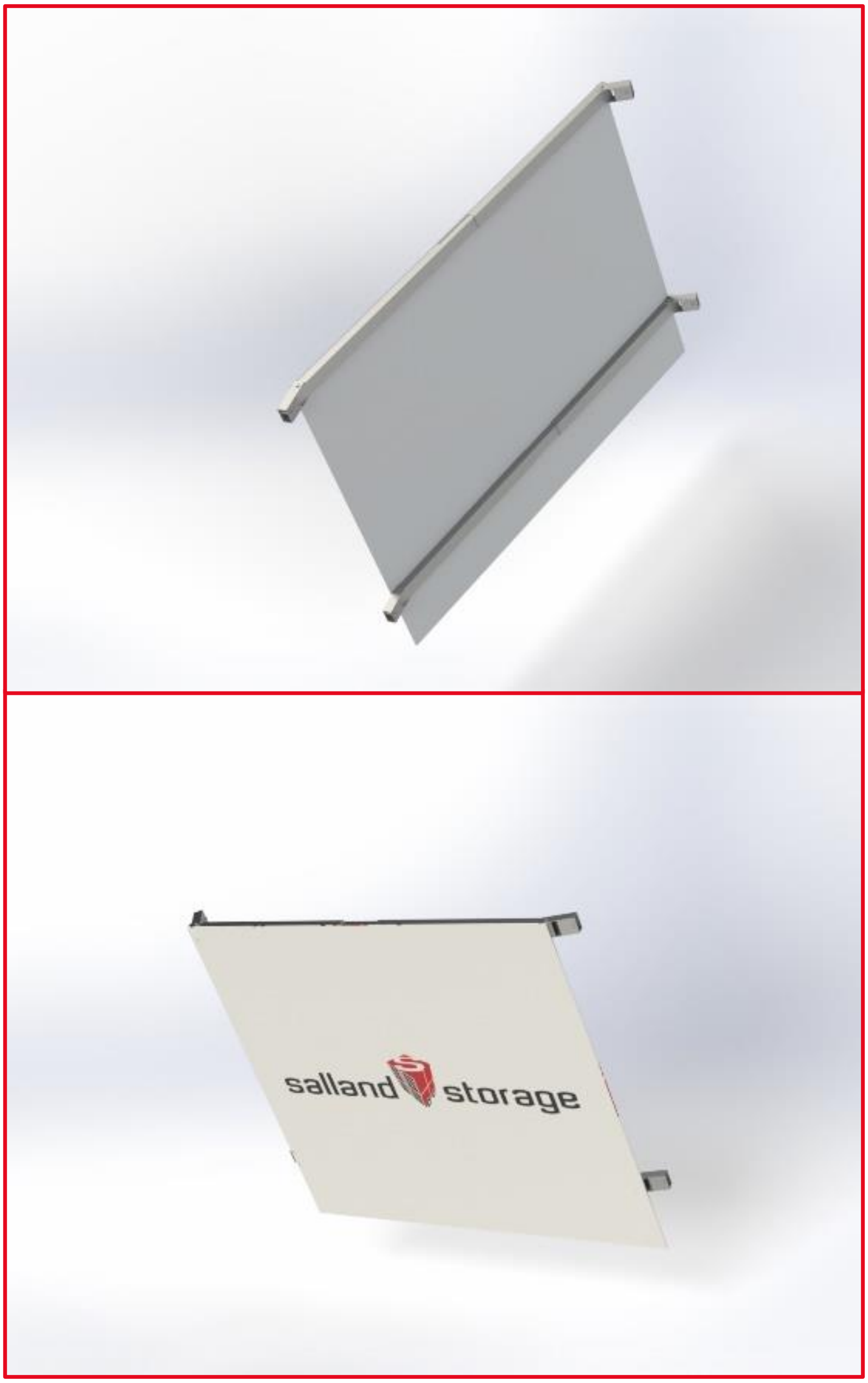


Figure 80 Railing with the billboard attached

6.3.4 Evaluation

While the aspects that make up the experience compass have been thoroughly researched in section 4.2, there are still uncertainties surrounding its effectiveness. After all, the literature did not explicitly state a linear scale spanning from uncomfortable to comfortable for instance. On top of that, some changes have been made to make the experience compass more suitable for use in the case of this two-story storage park. An example of this is the change from playful colours to ones more in line with the brand of the client.

In order to test the effectiveness of the experience compass, a survey was sent out. In order to increase the amount of responses, the survey was sent out to people that were not customers at the storage park in Deventer. This might seem counterintuitive but the customers at Salland Storage are a very diverse group of people, which means it is not as important that they are the ones filling in the survey. This survey first showed the renders of both the bridge and the stairs without any adaptations. People were asked the two questions. The first question was:

- Where would you say this structure belongs?

Where they could range their answer on a scale from 1 to 10. 1 Being exclusively at a playground, and 10 being exclusively at an industrial site. The second question was:

- How do you think you would feel when using this structure?

Here, people could answer on a range between completely unsafe & uncomfortable, and completely safe and comfortable. Subsequently, renders of the bridge and stairs with the adaptations included were shown, and the same questions were asked again. By averaging their answers, the progression can be seen on the experience compass in Figure 81. All answers can also be seen in Appendix G.

There are a few things of note here. First of all, both of the peripherals have moved closer to the average desired position, although the bridge not as much. The changes made to both the stairs and the bridge have made it noticeably feel safer. Possible reasoning behind this could be the fact that and bridges are mentioned to be locked in place and thus unmovable, and the fact that the bottom and sides of the stairs and bridge have been closed off. On top of that, the introduction of the black railings (likely in combination with the closed off space between the steps, has shifted the perception of the stairs as more toy-like, which moves it closer to the average desired position. Covering the metal structure and floor of both the stairs and the bridge will likely move it further down in cost, at the trade-off of cost. It is worth mentioning that this can be seen as a very promising result even though the bridge has not really shifted in its appearance. The removal of the playful colours like green and blue in favour of the brand colours of red, black, and white likely played a large part in the small shift for the bridge. Still, the stairs and bridges do not make up the entire storage park. The closed off look of the containers with the white and black likely moves the appearance of the entire two-story storage park even closer to the desired position. At the same time, the railings closing off the ends of the walkways will likely improve the perceived safety, similarly to the closed off side of the bridge. Lastly, the walkways being made up out of rubber instead of bare metal should also help bringing the appearance further toward the toy-like side.

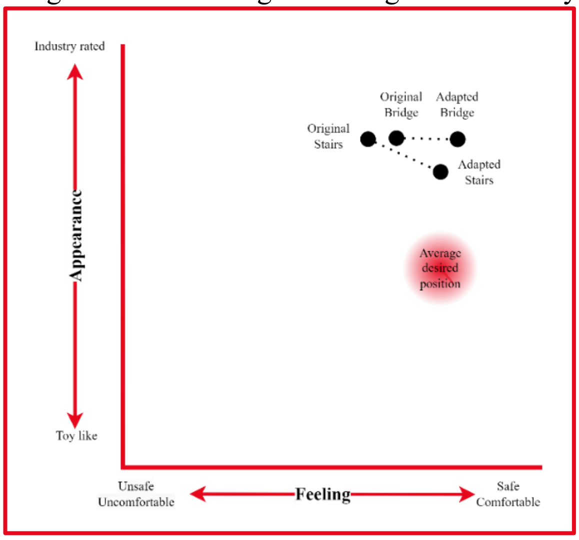


Figure 81 Progression of adapted peripherals

6.4 Requirement validation

At the end of chapter 2, two main requirements were set concerning the profitability, safety, and legality of the two-story storage park. The requirement concerning the profitability of the two-story storage park will be validated in a later phase of this thesis. This chapter has concerned itself with the other requirement:

"A permit of the concerning municipality (Deventer) must be acquired to declare the park as safe and legal."

This requirement cannot be outright validated currently, as a permit cannot be acquired at the current stage of the process. In order to acquire a permit for an unusual structure such as this one, an inspector will have to visit to witness the considerations made in person. Unfortunately, the current issues with the park, such as the uneven floor, prohibits the proper stacking as envisioned in this thesis. In confirmation with the client, they would also prefer to wait in order to make sure that not only the theoretical capabilities have been confirmed, but also the practical process can be shown to the inspector. Still, this entire section has laid down all of the groundwork for the confirmation of the two-story storage parks' capabilities. On top of that, the legislation as required for both the load-bearing capabilities as well as the railings combined with the added failsafes of the brackets should enable the client to acquire the permit after construction of a test setup. Therefore, this requirement can be considered achieved.

7 Case study

Now that the majority of different aspects for the development of a two-story storage park have been wrapped up, they can be implemented in a case study. This can be considered a final design phase before development of a real park can begin. There is unfortunately no viable way to develop this two-story storage park during the course of this thesis, due to the size of such a particular project. This case study aims to create a detailed layout plan of the design and get a proper cost estimation for the construction of such a park. A visual summary of this can be found in Figure 82.

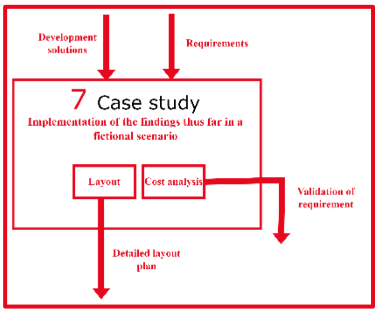


Figure 82 Plan of approach - Case study

The following key considerations will be considered in this section:

- *The driveway must be at minimum 3.5 meters wide.*
- *The crosswise sides of the model 2 Z-boxes on the bottom layer should face each other.*
- *The area over the driveways should be populated with bridging (model 2) Z-boxes.*
- *The sides of the top floor should be populated with (model 5) Z-boxes.*
- *A margin has to be taken into consideration for stacking the Z-boxes, as they won't always line up perfectly.*
- *The walkways need to have a width of at least 2 meters.*
- *The second floor should be accessible by use of stairs.*
- *All Z-boxes should be reachable from only one stairway.*
- *The driveway must have a circular flow, meaning that no car would have to reverse to get out of the storage park.*
- *The distance from entrance of the area to the stairs should be minimised*.

7.1 Layout

The perfect two-story storage park aims to implement all of the previous work done in this thesis. The area that this perfect park will be placed in will be a 100 m by 100 m square, with an entrance in the middle of one of the sides. When implementing the optimal layout researched performed in chapter 2 a total of 119 Model 2's and 30 Model 5's can be placed, bringing the total to 149 Z-boxes. This can be seen in Figure 83.

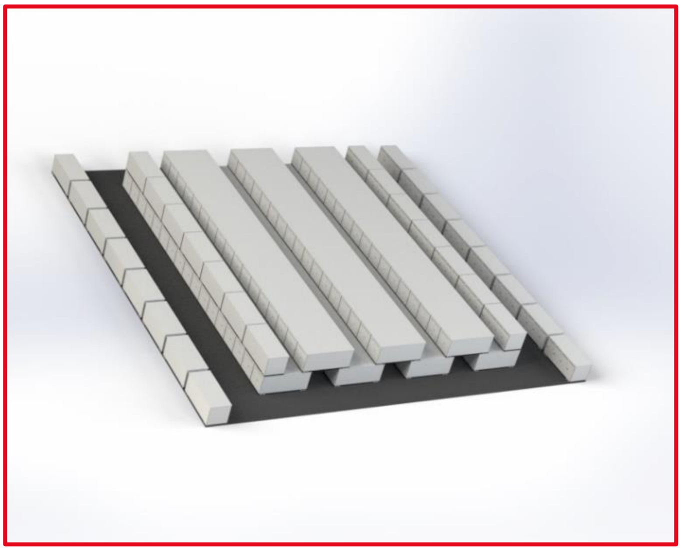


Figure 83 Full layout

All of the driveways are 3.5 meters underneath the overhanging model 2's, with more width along the edges of the park. To accommodate for the extra width of the stairs that will need to be installed, some Model 2's will have to be replaced by model 5 Z-boxes. This adaptation can be seen in Figure 84.

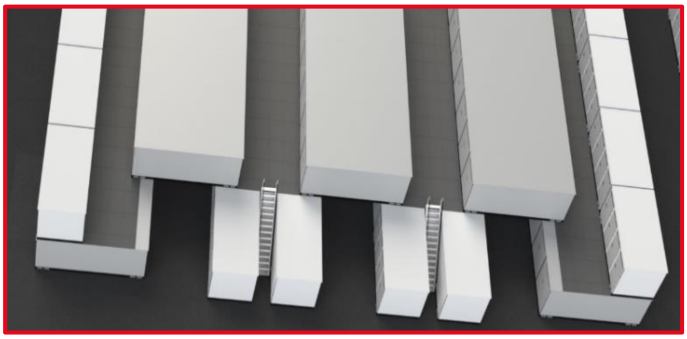


Figure 84 Adding the stairs

Making place for the stairs in the storage park required the removal of 7 Model 2's, but as the stairs can be flanked by 4 Model 5's, the total only gets brought down to 146. Adding the 3 bridges brings the total down to 143, as shown in Figure 85.

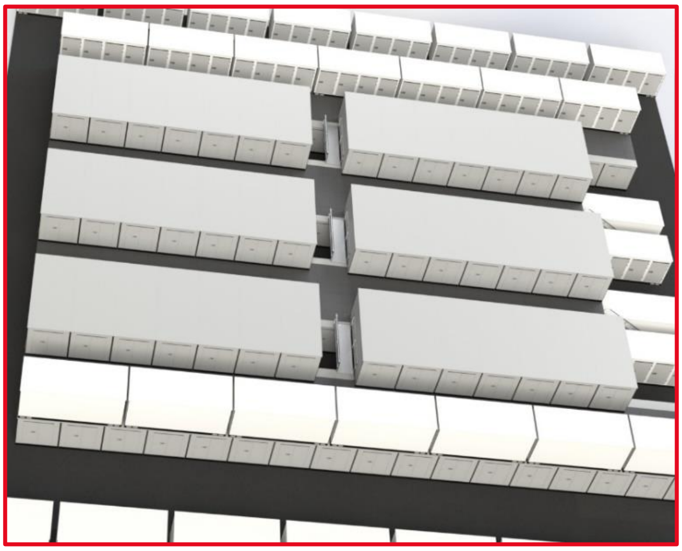


Figure 85 Adding stairs and bridges

Adding the railings is a bit more difficult than previously imagined. A combination of differently scaled beams can be used of the outermost edges away from the stairs, as seen in Figure 86.

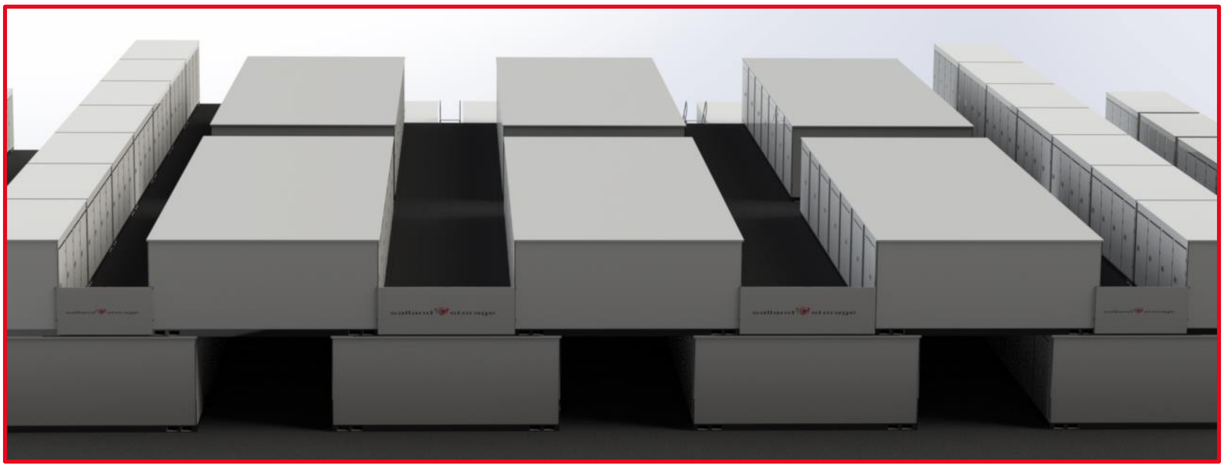


Figure 86 Railing on one end of the storage park

The main issue stems from the edge cases, namely the areas next to the stairs and the ones at the edge, indicated in Figure 87.

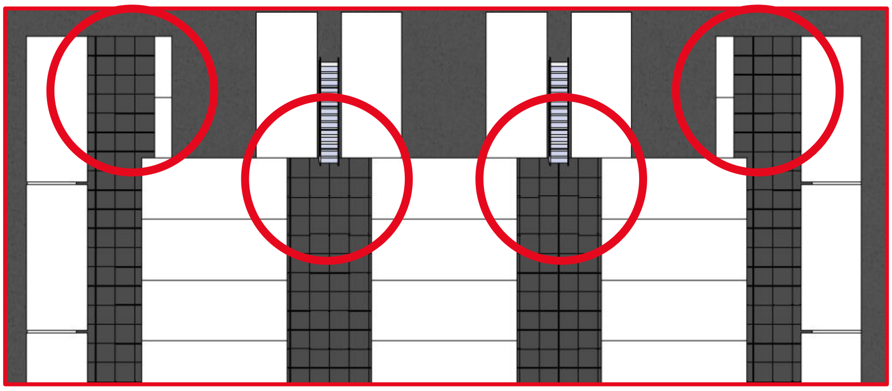


Figure 87 Railing difficulties

Both of these locations will be considered separately to find an attachment method for the railing. As with the development before, the following key considerations will have to be taken into account:

- *The railings closing off open areas should have a height of at least 1 meter.*
- *The gaps in the railings closing off open areas should not exceed 0.5 meters.*

7.1.1 Railing – stairs

Blocking off the open space on either side of the stairs is not as simple as with the ends of the walkways pictured in Figure 86. The main difficulty comes from the fact that there is no easy mounting point along the length of the barrier. Thus, two viable options remain for attaching the railing. Either placing a vertical beam to introduce a mounting point, or somehow attaching it to the stairs. The difficulty that comes with attaching the railing to the stairs mostly hinges on the fact that due to the rounded off shape of the handle makes it difficulty to line the railing up in a level way, as it might not line up exactly to the bolts on the corner of the Z-box. Therefore, the decision was made to place a vertical beam as an attachment. Normally, one can just buy a foot for a beam, but this leaves only one attachment point that will have to endure all the forces in the railing. Solidly attaching the vertical beam to the ground is the way to go. For this, the L-shaped bracket used for attaching the stairs can be used, as shown in Figure 89. This bracket can be used to place a vertical beam. The vertical aluminium beam will not be welded directly to the L-bracket, but a mounting point as shown in Figure 88 should be added. The final railing can then be placed as shown in Figure 90.

Figure 89 L-bracket for attaching the stairs

Figure 88 L-bracket with mounting points for vertical beam

Figure 90 Railings at stairs

7.1.2 Railing – edges

The other challenging space where railings will have to be added are at the corners of the storage park. Placing a diagonal beam from the overhanging Model 2 to the Model 5 at the edge will block access to the outermost door of the Model 5. Therefore, an L shaped aluminium beam must be placed, which can be supported at the corner. Due to the fact that the beam will be attached on both ends, it does not need to be fixed to the ground but can make use of a standard beam foot [33]. Due to the difficulties of welding aluminium, the corner should be constructed by making use of a top-clamp. [34]

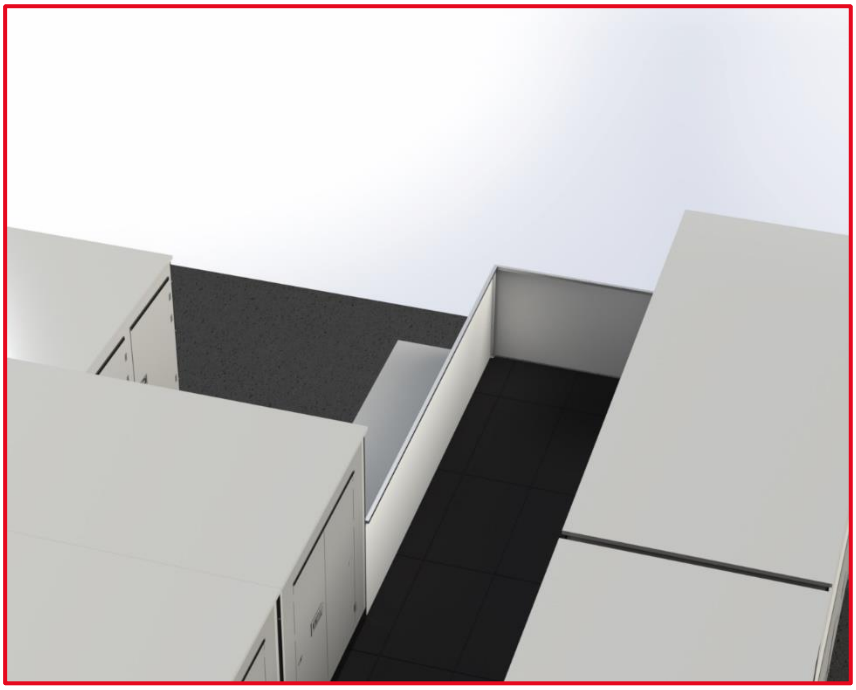


Figure 91 Railing at the corner edges of the two-story storage park

7.1.3 Railing – Stairs

The last area that needs a small alteration to the railing is the area near the bridge. Conveniently, this is where the previously designed railing beam can be utilized, as placing this railing at an angle does not diminish the usability of the top floor. Also, using the 'corner' type of boarding as developed in the previous section would require more material and would thus be more expensive without providing any extra usability.

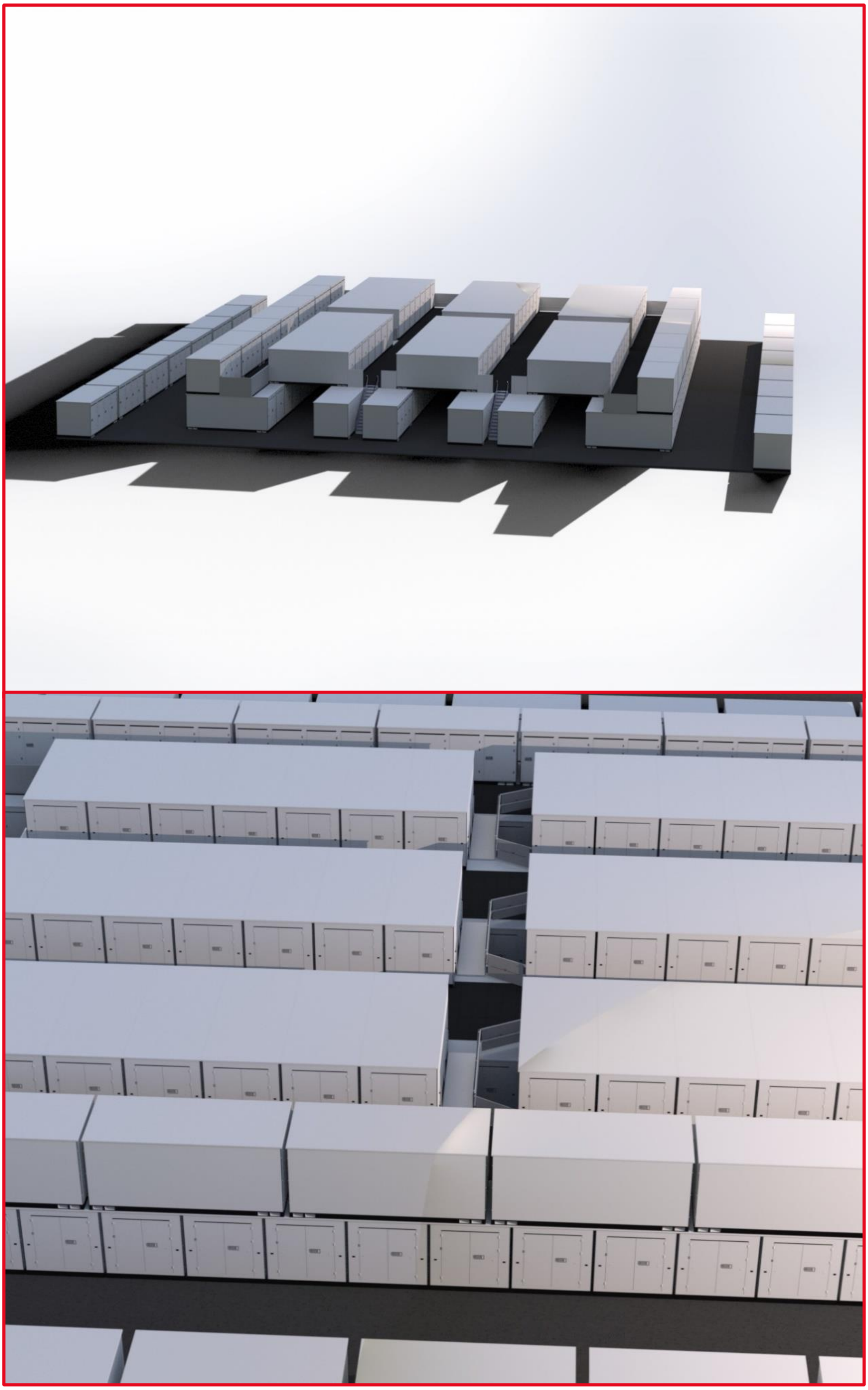


Figure 92 Additional renders of the two-story storage park

7.2 Cost analysis

As stated in the beginning of this thesis, the park needs to be profitable, safe, and legal. Both the safe and legal requirements have been worked into the design of the storage park itself and have thus been deemed satisfactory. While profitability has been considered during the decision making of the development steps, it has not been validated. Therefore, a Return on Investment (ROI) analysis will be done on the storage park. ROI can be calculated as follows [35]:

$$ROI = \frac{Net\ income}{Investment}$$

Here, the net income is the gross profit minus the expenses. The expenses can be classified by creating an expense report for construction and maintenance of the storage park envisioned in the case study.

7.2.1 Expenses

To create a proper cost analysis for this case study, a few things are of most importance. In order to determine the various expenses that come with the creation of this storage park, the first thing to do is create an expense report,. While the full expense report can be found in Appendix H, these are the various components:

- Bottom layer Z-boxes
- Top Layer Z-boxes
- Stairs Assembly
- Bridge Assembly
- Railing (Standard)
- Railing (Bridge)
- Railing (Corner)
- Railing (Stairs)
- Walkway
- Bracket L-L (set of 2)
- Bracket 2-2
- Bracket 5-2

There are a few things that are worth explaining. First of all, the man hours that are included use a base cost of €45 per hour, which the client was consulted about. This concerns the cost of the assembly crew, and not the freelancer used for the welding and creation of the brackets. Second, one must acknowledge that it is not reasonable to perfectly calculate all of the different expenses associated with the construction of this storage park. Therefore, a margin of error of 10% was introduced, as to compensate for the possible variations in cost. Lastly, maintenance costs should also be considered. Once again, in consultation with the client the yearly maintenance costs were set to around 3% of the yearly profit. All of this results in an initial investment of approximately €930.000.

7.2.2 Profit

The primary source of income is the rent of the Z-boxes. The website of Salland Storage shows the prices for both the Model 2 and Model 5, which are €79 and €39 per 4 weeks respectively [4]. However, as the market research performed in section 3.2.1 showed, the customers are generally not willing to pay the same price for a storage box on the second floor. On top of that, the simulations showed that a 10% reduction in base capacity has to be introduced. This also had to be included in the calculations. A base discount of 20% has been chosen, but this can be altered to study its effects on the ROI. On top of that, the model considers the park to be at a 90% capacity. While this number seems high initially, in consultation with the client, this number was confirmed to be in line with their other storage parks. Still, this number can be altered to study the effects on the ROI.

7.2.3 Period

In order to calculate the ROI for the storage park in this case study, one must first determine the time over which it needs to be calculated. After all, when only looking at the first year for instance, the amount of profit is still far too little to be considered a positive. The decision was made to take the lifetime of one Z-box as the period over which an ROI will be calculated, which would be 10 years. After this, the model assumes that the entire park is deconstructed and sold for scrap metal. While the Z-boxes will likely get more lifetime out of them provided that the maintenance costs will go up, there is currently not enough data to accurately predict the change in maintenance costs.

7.2.4 Results

With all of the aforementioned parameters set, the model shows a 140% ROI after 10 years, more than doubling the initial investment. The break-even point is then at a little over 4 years. According to the client, this break-even point needs to come earlier for them to consider investing. The suggestion was made that the prices of the different units should be higher. At their current price, they are already quite low on their profit margin, and they are considering raising them regardless. The decision was made to increase the price from €79 to €85 for the Model 2 unit, and from €39 to €45 for the Model 5 units. This brings the break even point down to 3.7 years, which was acceptable. The ROI would then be 161% after 10 Years.

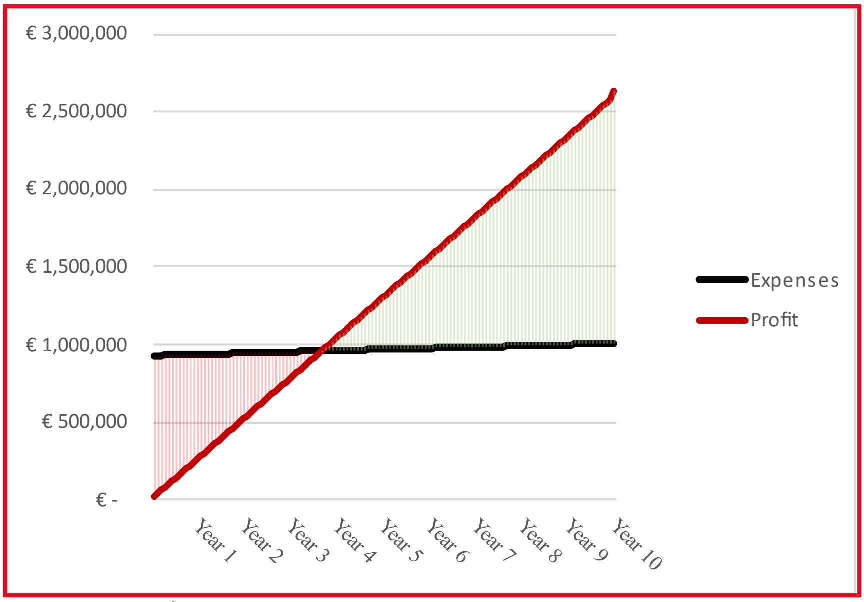


Figure 93 ROI after 10 years

The steeper increase at the end is due to selling all of the materials for scrap metal. The findings from this model prove that the construction of a two-story storage park is in fact a profitable manner, and thus is in line with the definition of a 'successful' storage park as stated in the research question.

7.2.5 Client notes

In order to fully determine the validity of the model, a meeting was held with the clients. The aim was to see what changes they would implement before using it to sell this storage park to a client. The following things were of note:

- "*While this model is of use for selling such a storage park to a ground owner, we would immediately point them to the fact that in comparison with placing a building on the ground, this park is scalable. That means that the client can first opt for constructing maybe a quarter of the park, or only the ground floor. This allows the initial investment to be much lower, while keeping the potential ROI alive.*"
- "*The model for the cost analysis behind such a storage park is definitely of use to show that the concept is viable. However, before fully using it, we would expand on it to also show the profits after the 10 years.*"

The client was satisfied with the model, but they would like to keep expanding on it in the coming time. In agreement with the client, the model was handed over to them, with the initial results being deemed more than sufficient for this thesis. Lastly, in collaboration with the client, an option to sell the boxes for residual value was also implemented in the model. This changes the peak at the end of the 10 years as shown in Figure 94.

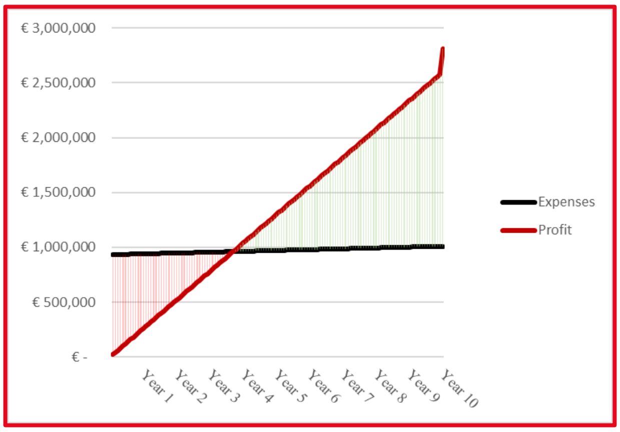


Figure 94 ROI after 10 years with the residual value implemented

7.3 Requirement validation

There were two reasons behind the development of this case study. One was finding out any possible issues, which became apparent in the form of the missing railings, and the other was to determine the costs. The model that was created to determine the profits can now also be used to confirm the following requirement:

> *"The profit of a two-story storage park per m^2 should be higher than a one-story storage park."*

This is done by removing the Z-boxes on the upper level, and all of the added peripherals that are required for the second floor (walkways, stairs, brackets, etc.) To properly compare both parks, a graph is created that shows the balance of the investment. This graph can be seen in Figure 95.

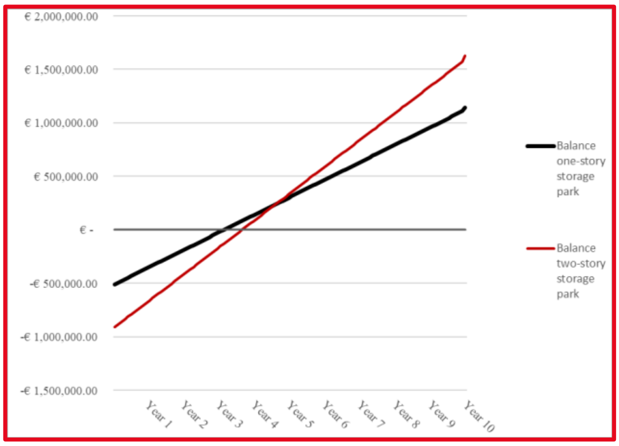


Figure 95 Balance comparison of a one-story and a two-story storage park

As can be seen here, while the initial investment of the two-story storage park is quite a bit higher, it becomes more profitable after year 5. This confirms the final requirement that makes up the research question.

8 Next steps

The entire plan for the storage park has been worked out in a theoretical manner in the case study, and several tests and prototypes have already been conducted in Deventer. There are still some ways to go in order to ensure the proper construction of the two-story storage park however. Coincidentally, this section is also the last key consideration that has not yet been explored.

- *Instructions for the construction of a two-story storage park the Z-boxes need to be present.*

This construction plan is written correctly identify any key areas of interest that needs additional testing.

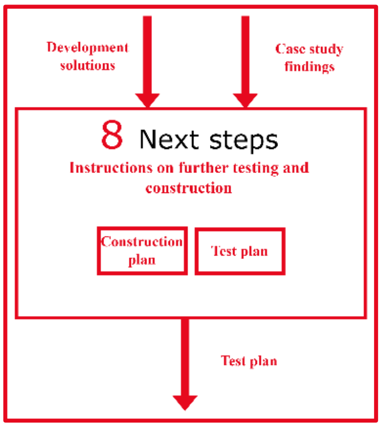


Figure 96 Plan of Approach - Next steps

8.1 Construction plan

1. The two-story storage park starts with a flat base. Currently, the ground outside in Deventer is far from flat. Salland Storage should therefore flatten the entire base at their storage park. Also, the recommendation is to remove the cobblestone, and opt for concrete plates. This will avoid future shifts due to uneven weights.
2. After the base is flattened, the next layer consists of the Z-boxes. Before placing the Z-boxes, the optimum layout has to be drawn out. This thesis already contains a suggestion that maximizes the usable Z-boxes. However, it is possible that Salland Storage might want to include other aspects such as more office parking spots.
3. Now that the optimum layout has been drawn out, it is time to start placing the Z-boxes. Here, the most important locations are the ones of the Z-boxes that face each other as these need to be perfectly in line. It would be most efficient to start placing the first Z-box, and then use something like a beam to perfectly line up the opposing Z-box (at a distance of 3.5 meter). As each subsequent Z-box will be placed up against its neighbour, they should line up automatically.
4. The stairs and flanking model 5 Z-boxes can now also be placed. This allows for easy access up to the top floor.
5. The drainage plates and walkway can be placed down now. This allows for part of the walkway to be under the top Z-boxes, securing it in place and covering the entire floor.
6. As the bottom layer is now placed, the top layer can be constructed. As before, lining the Z-boxes up is of most importance. Starting all the way at the back, the first overhanging Model 2 Z-box can be placed. Salland Storage needs to make sure that the feet have been lengthened to 120 cm as simulated in this thesis. The first Model 2 can be locked in place by attaching it to bracket 2-2. Once again, the rest can then be lined up by placing the Z-boxes tightly against each other, and securing them with bracket L-L. It should be noted that the bridge needs to be placed in between before continuing with the Z-boxes.

7. The Model 5's can now be placed along the edges. Salland Storage must make sure that the Model 5 rests on the edges of the lower Model 2's, by placing rubber tiles under the Z-box. Once again, the first can be placed by utilizing bracket 5-2. However, the Model 5's will likely not line up perfectly at both ends, and a small gap will be left in between them. This should be measured out beforehand.
8. All the railings, including the billboards, can now be placed. This finishes up the park.

These steps, according to the client, would take around 2 weeks *after* the base has been flattened, as this will take the longest time in the case of the storage park in Deventer. After the first two-story storage park has been constructed, a more detailed timeline can be created that can also be used to further adapt the cost analysis.

8.2 Test plan

When looking at the construction plan, it is important to consider which aspects still will have to be tested. The first step here is looking at the tests that have already been performed in Deventer.

1. The stairs have been fitted to the Model 2, with the two flanking Model 5's next to it.
2. Bracket L-L has been tested and confirmed to work and fit on the Model 5.
3. The Model 5 has been placed with rotated feet so that it is being supported by the frame of the underlying Model 2's.
4. The drainage plates and rubber tiles (walkway) have been confirmed to be comfortably walkable.

The following things still need testing before moving on to the full construction of a two-story storage park..

1. Lining the Z-boxes up in an optimal manner – spaced 3.5 m apart.
2. Attaching the bottom Model 2 to the top Model 2 by using bracket 2-2.
3. Attaching the bottom Model 2 to the top Model 5 by using bracket 5-2
    a. *Note: this test was already being performed near the completion of this thesis. The findings of this initial test are described in appendix I.*
4. Attaching the bridge to the Model 2's by using the holes as pictured in section 6.3.2.
5. Attaching the stairs , with the adapted L-bracket for the railing.
6. Constructing & attaching the railing at the stairs
7. Constructing & attaching the railing at the corners
8. Constructing & attaching the railing at the ends of the walkway
9. Testing bracket L-L for the Model 5 that are spaced further apart.
10. Lengthening the feet of the overhanging Model 2's to 120 cm.
11. After more overhanging Model 2's have been placed;
    a. Testing if lighting is needed inside the tunnel.
    b. Checking if water drainage is needed under the tunnel.
    c. Defining the fire escape routes and creating visual representations of those for the customers.
    d. Determining the need for extra safety devices for cars such as bollards or height limiters.
12. Considering a method to reduce the capacity of the upper Z-boxes by 10%

Once these things have been tested and confirmed, the client should start the construction of the smallest two-story storage park that still includes all of the aspects of a full-sized one to iron out any remaining issues. Depending on the availability of the assembly crew, the client estimates that finishing up this testing will take around 2 months.

9 Conclusion & Recommendations

9.1 Conclusion

The performed thesis was commissioned by a self-storage company called Salland Storage, who desired a method that allowed them to stack their storage boxes (Z-boxes). This would basically doubling their usable footprint, essentially making the parks more profitable. The research question posed at the beginning of this thesis was:

"How can the Z-box successfully be rented out by Salland Storage while stacked two high?"

The main driver here is the word 'successfully'. In consultation with the client, 'successfully' means profitable, safe, and legal. The process of answering this question started off by building a solid understanding of the current state of the two-story storage park, optimal layout possibilities, and researching different legislations that would have to be considered. This researched concluded with the formulation of two base requirements, covering the three important parts of success.

"*The profit of a two-story storage park per m^2 should be higher than a one-story storage park.*"

&

"*A permit of the concerning municipality (Deventer) must be acquired to declare the park as safe and legal.*"

Both of these requirements were backed by a set of key considerations that could be referenced to throughout the thesis. One of the key considerations was concerned with the load-bearing capacity of the Z-box to support the upper level. A thorough set of simulations showed that simply stacking them without any alterations could cause the structure to fail when the top Z-boxes were loaded to their maximum capacity. This already created a solid understanding of what the development phase would be about. Following that, a closer look was taken at the way of how customers would experience the park. Literature research gave a lot of solid pointers, yet no clear and concise answer as to what would improve the experiences for the customers. A tool was then created to be used at a later stage in the development. The main issue with the development of the park were the problems that were raised during the simulations of the load-bearing capacity. This resulted in a second round of simulations where it was discovered that by strategically spreading the load, the Z-boxes would be able to carry most of the weight of the top layer. Other objects that were developed in this chapter concerned a series of bracket designed to hold the Z-boxes together under the influence of external forces. The tool for the customers' experiences, called the experience compass, was also implemented in the development phase. It was used to strategically alter sections of the off-the-shelf peripherals such as the stairs and bridges in a way that would bring the experience of the two-story storage park closer to the optimal experience as desired by the client. An evaluation following that proved the experience compass to be effective. The development phase was also sufficient enough to validate the requirement regarding the permit. While no actual permit has been acquired due to the current state of physical progress, the theoretical backing was considered sufficient for now.

All of the work done in the prior sections came together in a case study. Keeping all of the lessons learned throughout the thesis in mind, a proposal for a fully functional two-story storage park could be created. With that, a proper cost analysis could also be performed. This cost analysis not only proved the fact that a two-story storage park was profitable, but also that it was more profitable than a one-story storage park in the same footprint as stated in the initial requirement. With those two requirements validated, the research question can be considered answered. In order to rent out a successful two-story storage park, Salland Storage can use all of the conclusions drawn in this thesis. Chapter 8 also lays out a set of instructions of the various critical components that would have to be tested prior to construction. These instructions can obviously be iterated upon should any problems rise up. For that, they can still build upon the lessons learned in this thesis.

9.2 Recommendations

This thesis has outlined the critical components that Salland Storage would have to consider and the steps they would have to take in order to rent out their first successful two-story storage park. This section will cover some uncertainties that remain.

9.2.1 International expansion

While some parts of the legislations that have been considered were drawn from the Eurocode, concerning the entire European Union, a large part of them have also been focused on the municipality of Deventer. It is likely that building this storage park in a different municipality will not change the majority of the legislation considered. This situation can change when Salland Storage or USC wants to sell this park outside of the Netherlands however. One example would be Germany. Obviously, the permits in Germany will differ slightly from the ones in Netherlands, and according to the client the permits in Germany are a lot harder to acquire. They also stated that they would not accept the load-bearing simulations done in this thesis and would instead use an external firm to redo them. This likely will cause the initial investment to increase. Another issue that will arise when building such a two-story storage park outside of the Netherlands is concerned with the transportation costs. While the Z-boxes have been optimized to reduce shipping costs, the other peripherals such as stairs and bridges might not have had the same amount of optimalization. This would once again increase the initial investment and would cause the break-even point to shift. Salland Storage should decide whether or not it is worth it to invest in this. Lastly, Salland Storage should also consider the different climates that an international expansion brings with it. An expansion to Germany might not matter as much, yet one Sweden does. This mostly comes down to the snowfall that occurs in those countries, which can significantly increase the loads on the top of the Z-boxes. New simulations should be performed that take those into account, with a possible plan set in place to remove the snow if it reaches a certain thickness.

9.2.2 Different layouts

This case study made use of a 100 m x 100 m square area, which was an arbitrary size. In the future, when Salland Storage is defining the layout for a two-story storage park, it will likely not be a perfect square. When using the same 1 ha area, the size could also be 50 m x 200 m. The key considerations for the layout laid out in the beginning of the case study should still allow these different layouts to be designed in a functional manner. However, with a length of 200 m, the walkway might become so long that either more bridges or more stairs will have to be implemented. These adjustments should be looked at separately for each different park.

9.2.3 Experience compass

The experience compass created in this thesis proved to be effective in adapting the peripherals to change the overall experience of the customers. There are still some improvement that could be made in order for the experience compass to be used effectively in other projects.

First of all, the experience compass can still be expanded on. Some aspects that might have been left out of the research performed in this thesis may be of use for other projects. An example could be claustrophobia, or fear of the dark. This means that the experience compass can constantly be added to in order to make it more effective.

For this project, the experience compass was a bit broader than might have been necessary in the case of this two-story storage park. As chapter 6.3 showed, not all of the different blocks were of necessity in the adaptation of the peripherals. In the same manner, the cost section was not utilized either. However, other projects might need the different aspects after all. This is the reasoning behind keeping the scope of the experience compass rather broad.

The exact definition of the bars that make up the axes are also subject to change with a likely hit to the effectiveness. An example would be the change to the colour scope by moving away from playful colours such as green and blue for a more neutral white and black. One could have made all of the peripherals neon-green and shift the experience of the customer significantly to the toy-like side. Yet, this would severely clash with the black and white Z-boxes at the core of the two-story storage park.

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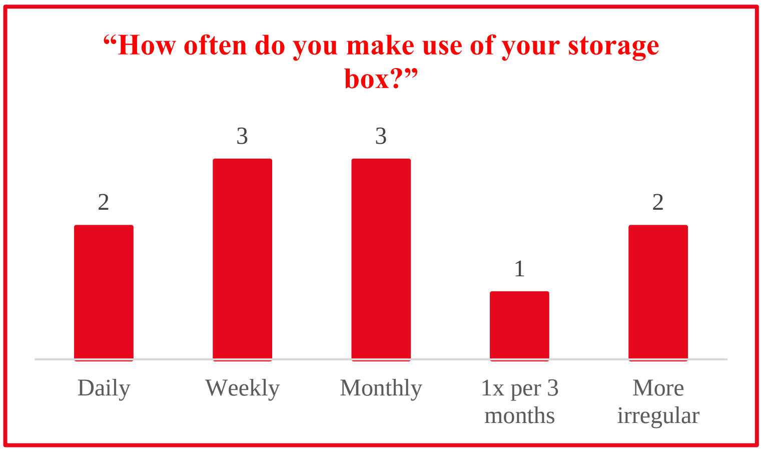
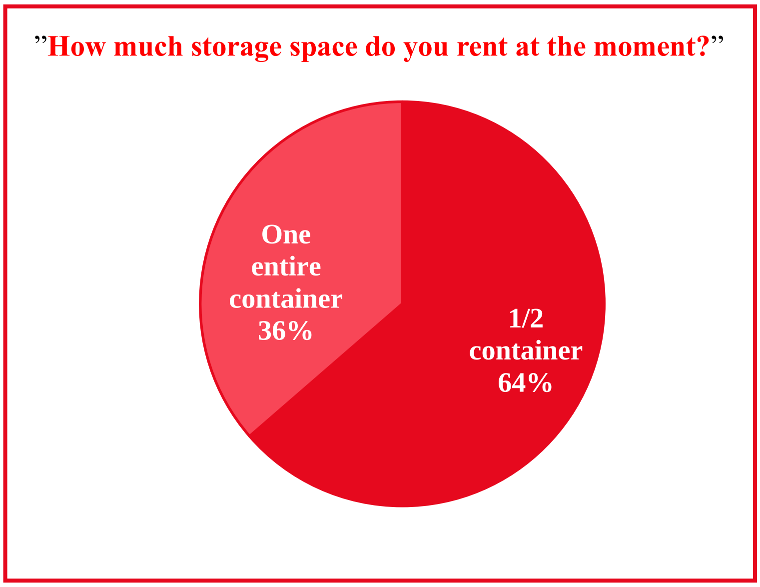
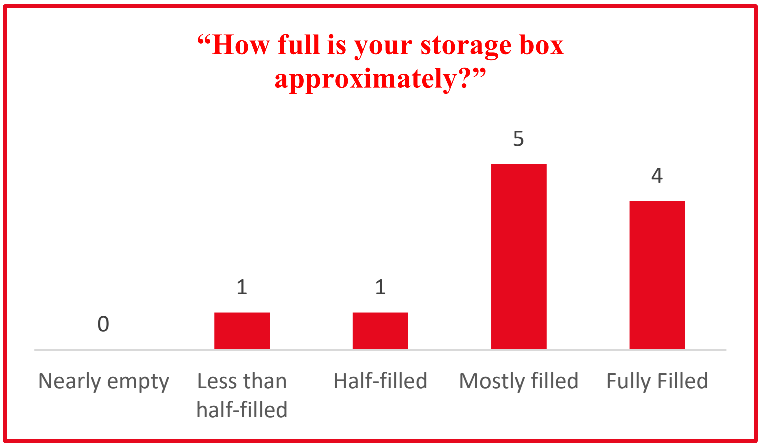
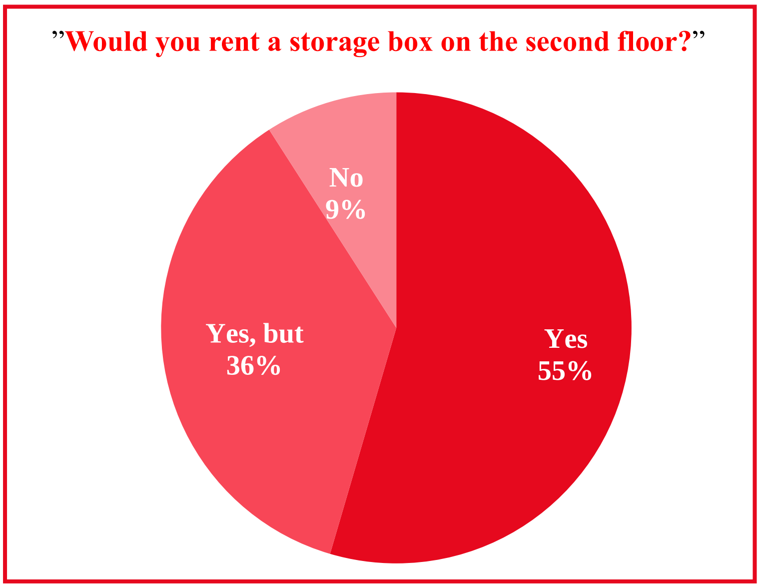
Appendix

Appendix A: Market research results







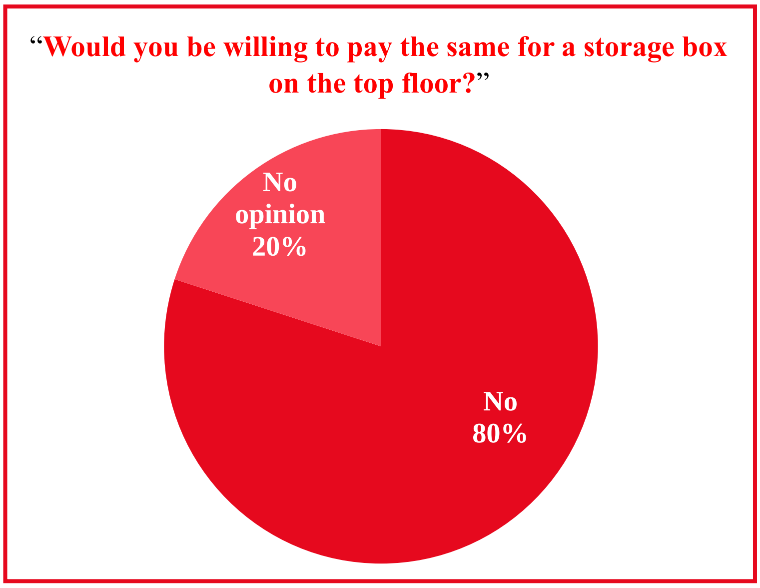


The general problems for the people saying outright “no” were:

- People with a motorcycle
- A storage box on the second floor would not be easy to unload or load.
- The top floor is more difficult to reach.

The people who said “yes, but” mentioned the following considerations:

- As long as the stored stuff is not too heavy/ difficult to move (and if it is, there should be a ramp or lift)
- As long as it is reachable without too much hassle.
- As long as I don’t have to load/unload frequently.



Appendix B: Experience Compass

B.1: Cost analysis

While the cost is not the leading factor for the optimal location on the experience compass, it could be useful. Since the optimal location is mainly subjective, there is still some room to move around, it is not a fixed point. Adding the cost into the compass can then help understand what the influence of slightly different design directions does to the total cost price.

Simply looking at the cost might appear quite vague, but there are some pointers that can help along the way. A lot of structures that appear industrial show the different trusses and load bearing components quite well, as they appear quite bareboned. These load bearing components are also used in the more toy-like (yet still safe) structures, but they are covered with different materials, such as rubber or brightly coloured plastics. These materials serve no other purpose other than making the structure seem more approachable, yet they add cost.

At the same time, cost also has an influence on the feeling axis. Consider a pool hanging over the side of a building with a glass bottom. While the architect will have no doubt considered the load bearing capabilities and declared it safe, it still feels a bit dangerous. If one where to add a large amount of material under it, it would seem much more structurally sound, but also increase the cost.

An average summary of these findings on cost is visualized in Figure 97. It should be noted that these conclusions are not empirically backed up and are therefore more taken as a reference.

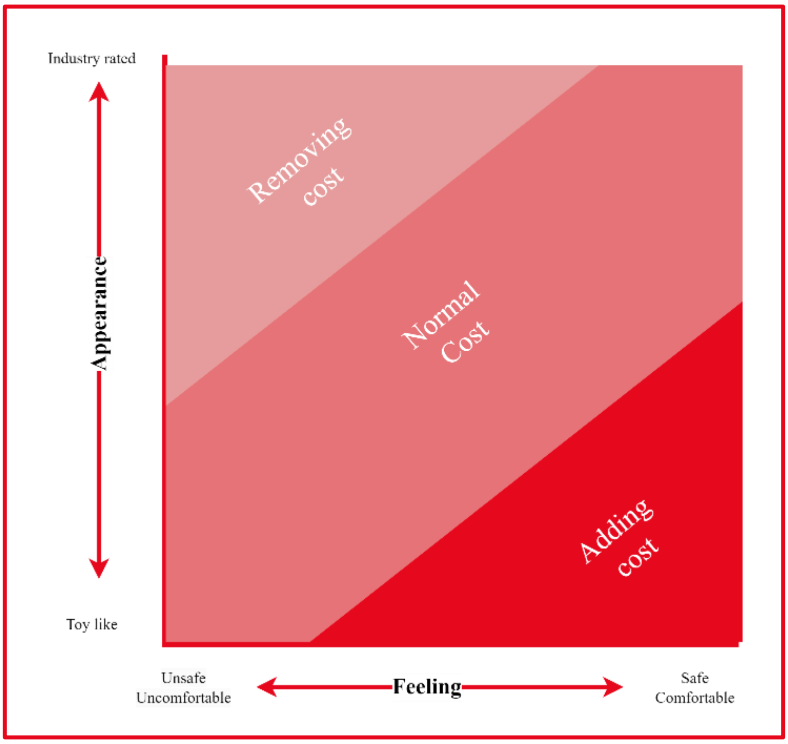


Figure 97: Cost integrated into the experience compass

B.2: Optimal locations

As mentioned in section 4.3, both of the CEO's needed to mark their optimal location on the experience compass. To accomplish this, both of the CEO's were approached independently, with the two basic axis left empty of all the different blocks. They were asked to mark their desired spot, without any explanation regarding the compass itself. Figure 98 shows the independent locations of both (JHS & MS) with their average.

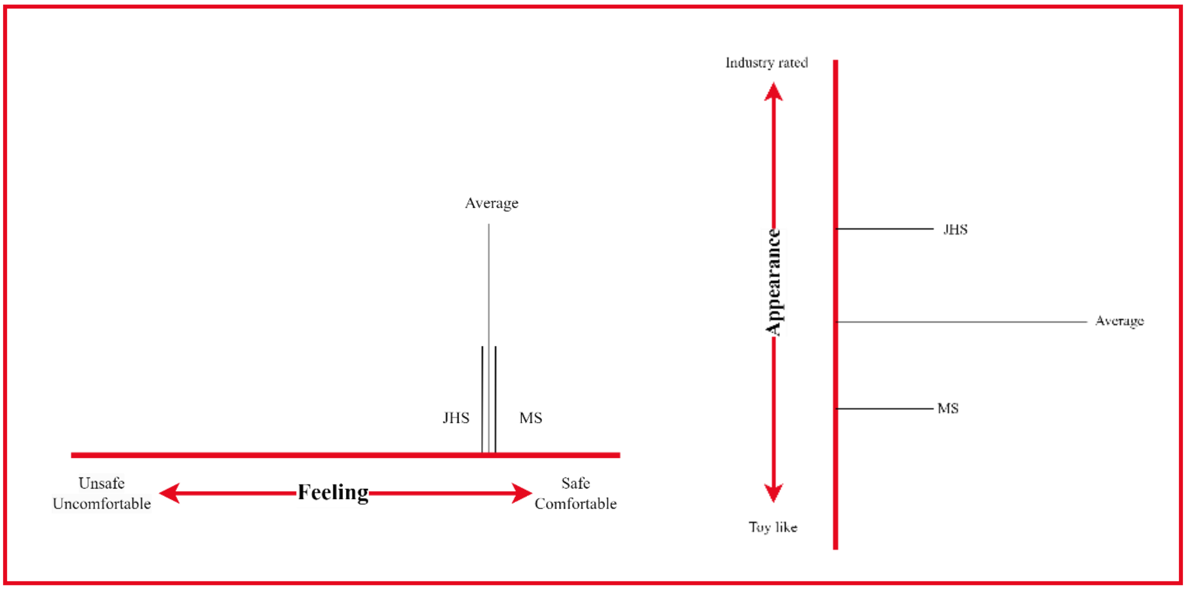


Figure 98 Independent locations on the Experience compass axes

Some interesting observations are described below:

- Both JHS & MS prefer the safer side of the feeling axis, yet they both refrained from placing their optimal locations on the far right. When asked about this, they both mentioned that they don't want to make people feel too comfortable, as it can always be dangerous when walking around with heavy items on the top floor, and proper precautions should be taken.
- Both of the CEO's had a very different opinion on the optimal appearance location. MS explained that he felt that the Z-boxes already had a sort of 'toy-like' appearance and thus going for that side of the appearance graph kept the brand language consistent. JH explained that he felt that an industry rated structure might make people feel safer as JH mentioned that most industrial structure feel sturdier, while still encouraging users to keep the aforementioned safety precautions in mind.

Appendix C: Q235 material data

The structural report from USC reveals that the steel used in the frame is called Q235. It does not note enough information to fully define the material however, so that has to be done by hand. According to CNClathing [36], Q235 has the following properties:

- Ultimate Tensile Strength: 370-500 MPa
- Yield Tensile Strength: 235 MPa
- Elongation at Break: 20-26%
- Modulus of Elasticity: 200 GPa
- Compressive Yield Strength: 152 MPa
- Bulk Modulus: 160 GPa
- Poisson's Ratio: 0.26
- Shear Modulus: 79.3 GPa

The structural report did note that the flexibility modulus was 196 GPa, so that was altered in the material database. The density of 7.85 kg/m^3 was retrieved from another source [37]. These numbers together were used to create a new material in Solidworks as seen in Figure 99.

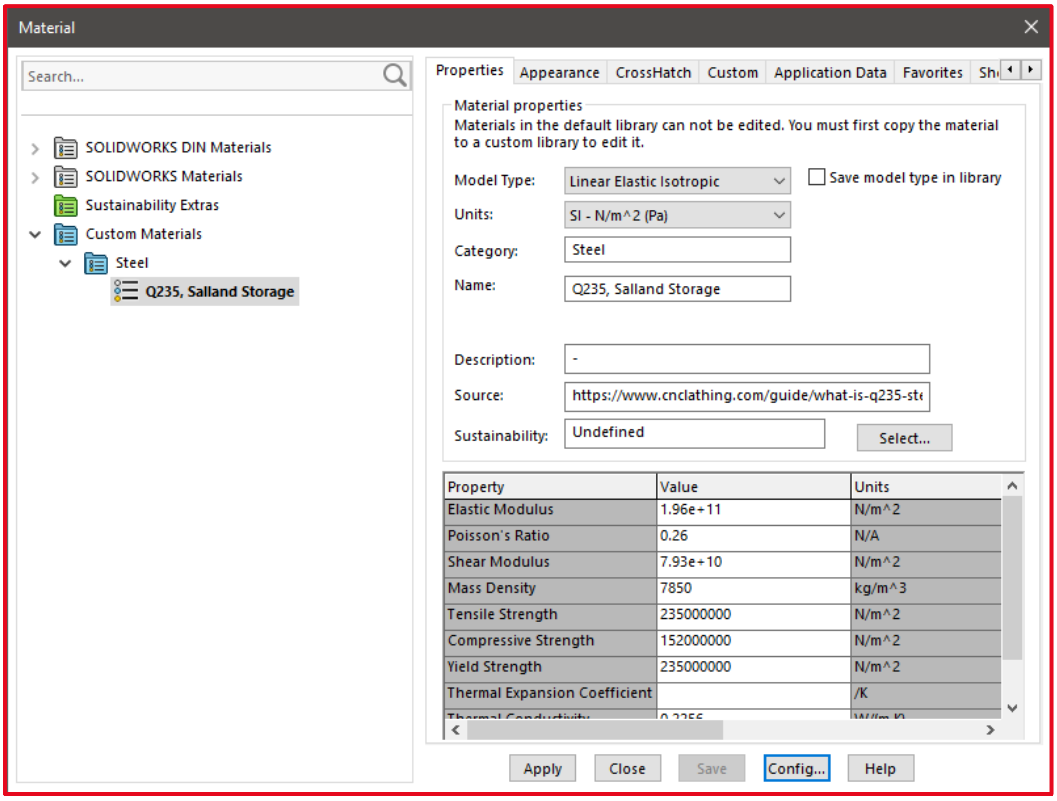
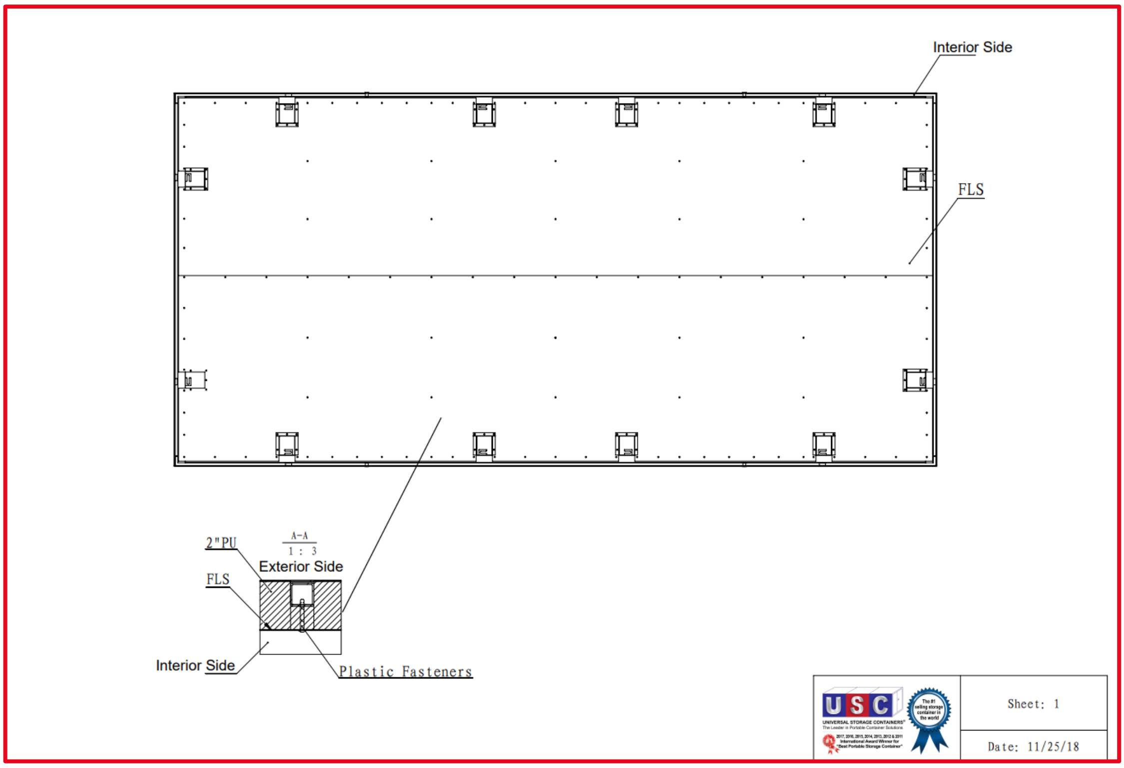
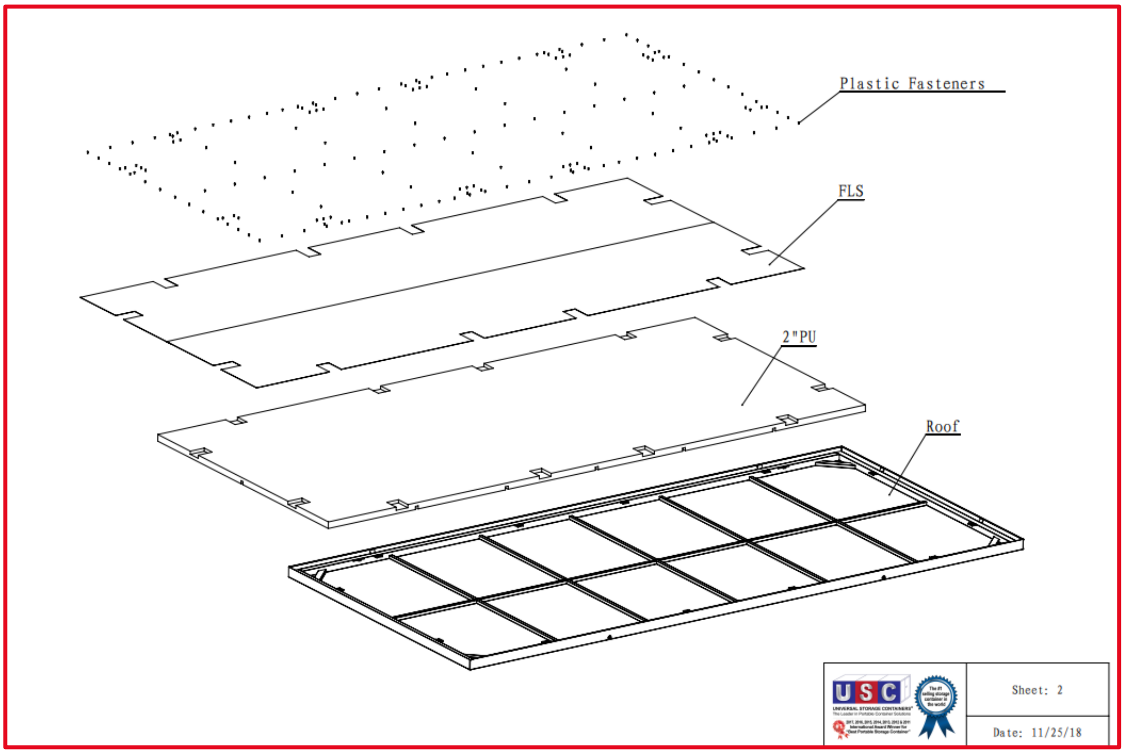


Figure 99: Material properties entered in Solidworks

Appendix D: Roof Drawings





Appendix E: Elaboration on brackets

E.1 Attaching the lower Z-boxes to the ground

As stated in chapter 6, the client would prefer the Z-boxes to be mounted to the ground yet could give no clear indication as to why. Mounting the Z-boxes to the ground is in a way easier to design as the other brackets, simply due to the low number of variables at play.

Existing anchors

To garner inspiration, a look is taken at the anchoring of shipping containers to the ground. There are two main components to this principle: Attachment to the container, and attachment in/to the ground. The attachment to shipping containers is often done as follows [38]:

Figure 100 Shipping container ground anchors

This simple casted metal piece is placed into the shipping container, rotated 90 degrees, and is then bolted to the ground. Seeing as it relies on an asymmetrical hole, it cannot be attached to the Z-boxes in the same manner. This piece could be used as a starting point for a new design, however.

Another way of attaching things to the ground are by the use of ground anchors [39], pictured in Figure 102. These anchors are used to be placed in concrete. This is not a viable or reliable method for most of the storage parks (that mainly have soil underneath). Therefore, a different approach would need to be taken in that case. When anchoring scaffolding to a soil underfloor, anchors as shown in Figure 102 are often used.

Figure 102 Concrete Ground Anchor

Figure 102 Soil Ground Anchor

Mounting location

As the vast majority of the Z-boxes that need anchoring are the model 2', the sides of the boxes are obstructed from being used. This leaves the frond and the backside as the main mounting points.

Figure 103 Bottom of crosswise side Z-box Model 2

The best place to then anchor the Z-boxes to the ground would be the two square protrusions to either side of the front. These already have a hole for a locking pin, but in its current configuration, it is not used for anything.

Figure 104 Square protrusions for attaching ground anchors

E.2 U-bracket iteration

The main issue with the u-bracket was the fact that it relied too much on a near-perfect alignment of the neighbouring Z-boxes. This alignment is not perfect in a real-life situation, not only in the difference in width between the gaps, but also a slight differences in between the mounting bolts is possible.

For solving the alignment issues between the bolts, the holes in the u-bracket can simply be changed to slots, as can be seen in .

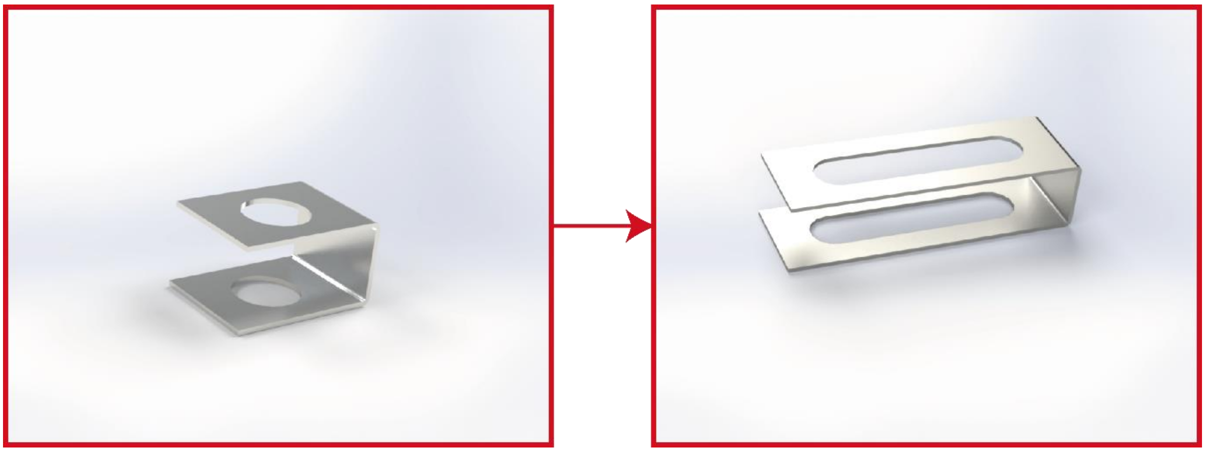


Figure 105 U bracket iteration

This does not solve the problem of the width in between the Z-boxes however. The u-bracket has to be either flexible (and thus expensive) or split into two parts to solve this. This would then look something like the following figure:

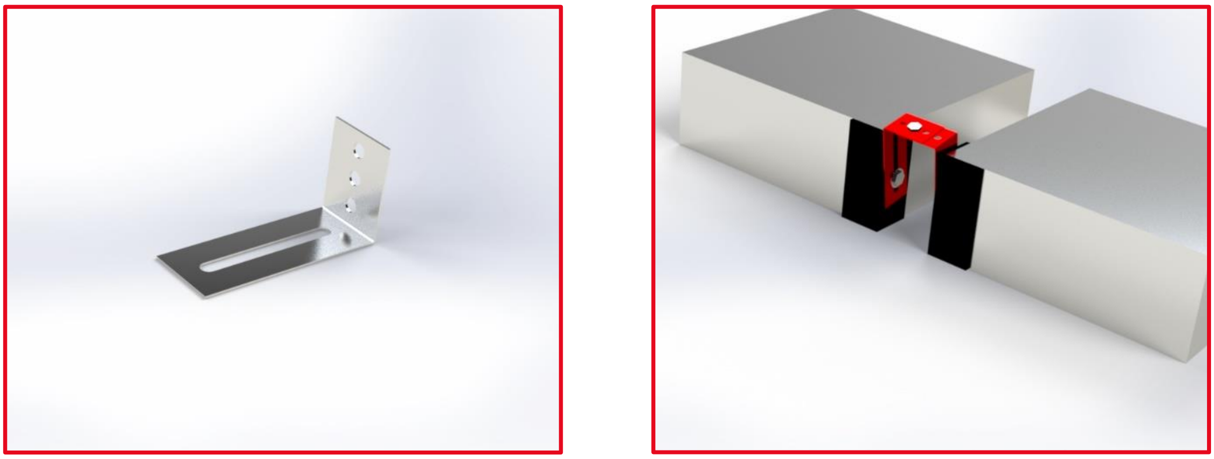


Figure 106 U bracket final design

This does remove a large part of the material and thus hurts the strength of the bracket. The decision was therefore made to not pursue this concept any further.

E.3 Strength test (Bracket L-L)

In order to validate the strength of the brackets, another Solidworks simulation was performed. For this, the extreme example of a car driving into the floor of an overhanging model 2 z-box is used. A vehicle that is high enough to be able to cause this crash would be a Ford Transit L2H3 [40], with a height of 279 cm. Its dry weight is around 2100 kg, so with a driver and some goods already in the vehicle, this would round out to approximately 2300 kg. For the speed of the vehicle, the maximum speed at the storage park in Deventer is chosen (15 km/h). This would equal 4.1 m/s.

As is known $\vec{F} = m\vec{a}$. The acceleration (in this case, deceleration) depends on how quickly the vehicle is brought to a stop. This is very difficult to predict, but the formula for impact force can also be described as $F = \frac{mv^2}{2d}$ [41] . Here, the "d" in the equation is the stopping distance. An approximation of 20 cm is taken, as sort of a "crumple zone" for the roof. The formula would then be as follows: $F = \frac{2100*4.1^2}{0.4} = 88kN$. This is then spread over 2 contact points (as the model 2's is connected with 2 brackets, resulting in a 44 kN force per bracket).

When simulated with this force, the bracket fails, as can be seen on the figure below:

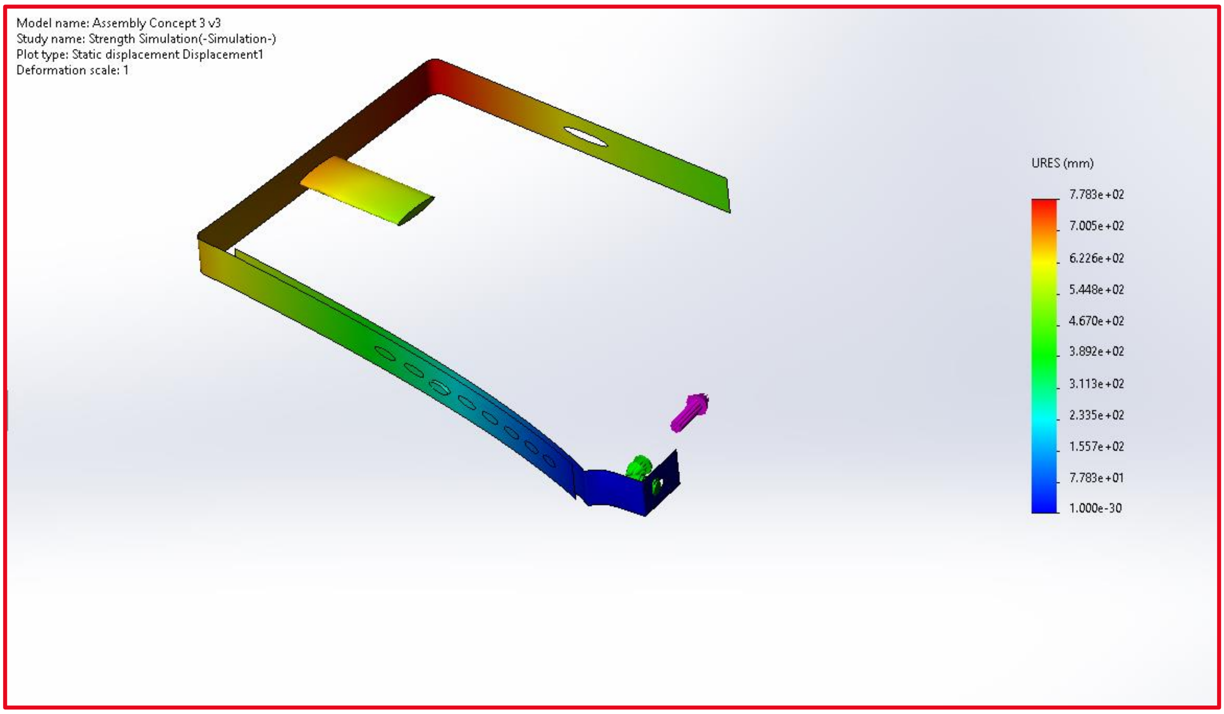


Figure 107 Simulation of Ford Transit impact on Model 2 bracket

E.4 Cost analysis (Bracket L-L)

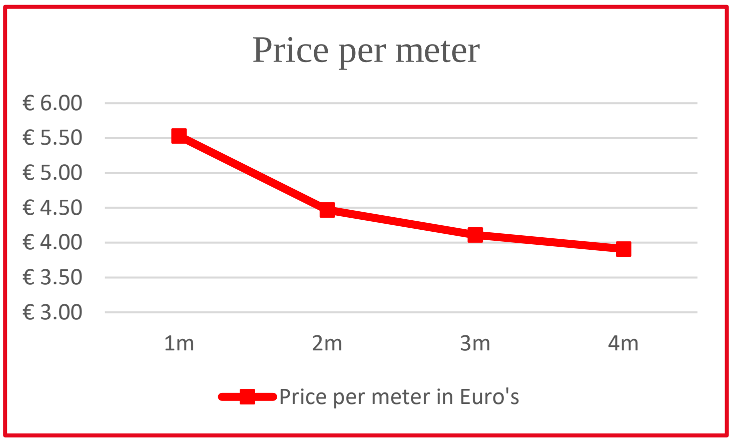


Figure 108: Price per meter of 50 mm steel strip

With the brackets constructed, the total cost of the bracket can be calculated. Both the drilling of the holes and the bending of the sheet metal was done at Salland Storages workshop.

When unfolding the model into the flat strip of metal, the total length is 500 mm (425 mm plus a margin), with a width of 50 mm. When filling this into the ordering page of a steel web shop called Staalvakman [31], the total cost of one bracket worth of metal strip is equal to €5.53 This is because of the fact that everything under 1 meter seems to cost the same amount of money. Ordering longer strips change the cost as shown in Figure 108. This shows that ordering larger strips of metal is cheaper in comparison.

In order to compare the price of a ready cut strip as opposed to cutting it at Salland Storage, a cost comparison can be made. For this, a freelancer at the company who also created the final model of brackets is considered when comparing costs. The freelancer costs the client approximately €50 an hour. He was asked to fill in the following table.

	Time	Pre-cut Strips	4 m Strips
Material Cost	-	€5.53	€1.95
Cutting the Strip to size	0.5 min	-	€0.42
Drilling the holes	15 min	€12.5	€12.5
Bending on press brake	5 min	€4.17	€4.17
Assembly & Installation	5 min	€4.17	€4.17
Total per bracket	-	€26.36	€23.20

Table 11 Time cost for bracket 2-2

This shows that ordering the larger quantities of metal uncut is the cheapest option for the bracket, bringing the total price to €23.20 per bracket. The freelancer did note that these times will likely come down when a multitude of brackets is made, and some tasks can be optimized as a result.

E.5 Cost Analysis (Bracket 2-2)

The first thing to figure out to calculate the total cost is the total length of steel needed. The total length of the entire tube (without the diagonal cuts for welding) is equal to 193 cm of steel. With a margin, this rounds out to 200 cm. A 2-meter beam (40 x mm 40 mm x 4 mm) costs €25.92 at the aforementioned retailer, but this would need to be cut into the separate sections. The retailer also allows the sections to be bought precut at an angle, but this costs extra. Buying the sections precut would result in the following cost:

	Time	No. of angled ends	Cost
Section 1	380 mm	1	€14.88
Section 2	120 mm	2	€15.84
Section 3	180 mm	2	€15.84
Section 4	700 mm	2	€15.84
Section 5	200 mm	2	€15.84
Section 6	200 mm	1	€14.88
Total	1780	-	€93.12

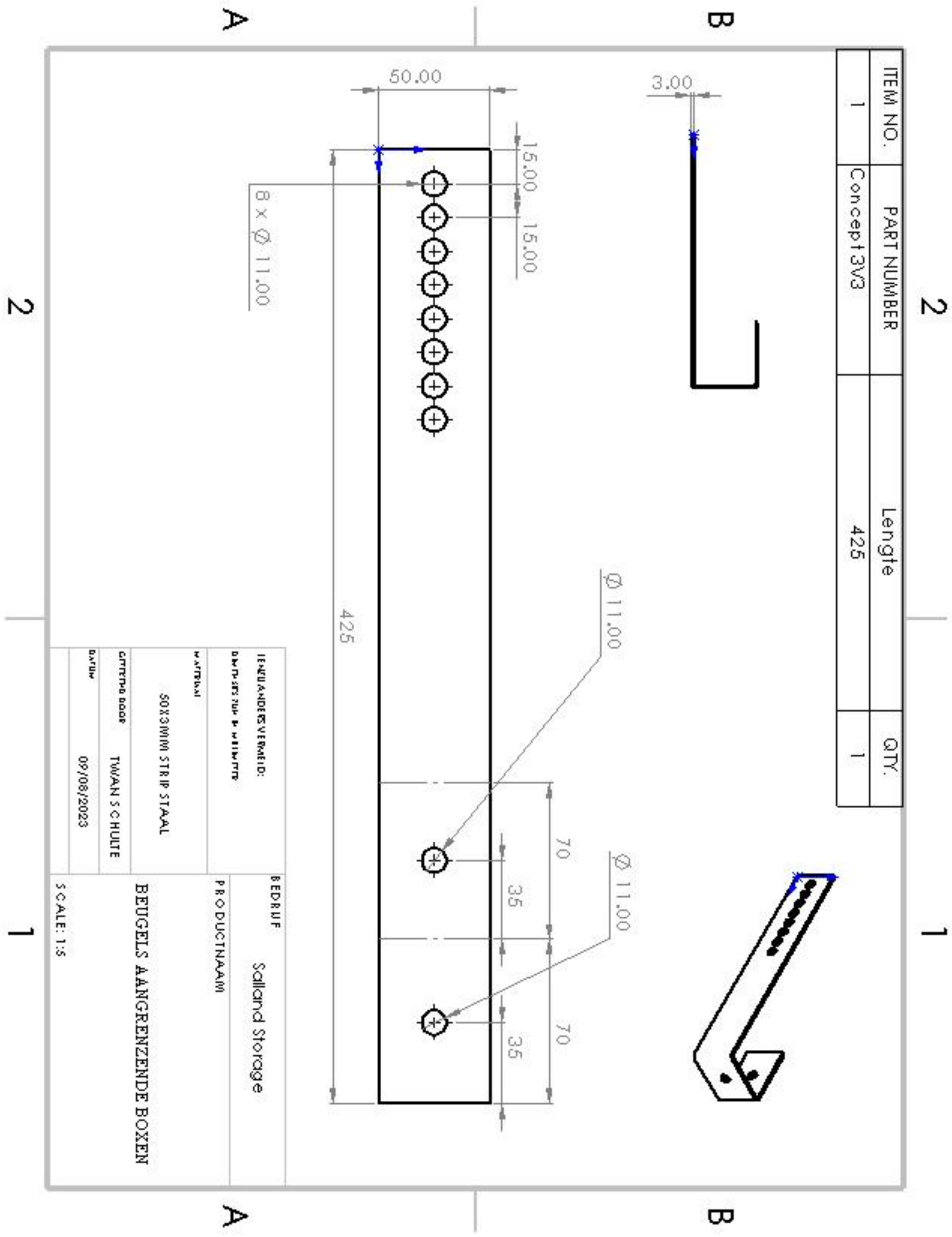
Table 12: Cost comparison Bracket 2-2

This difference of €93.12- €25.92= €67.20 is equal to more than an hour of work of the freelancer at the company to cut this himself. The retailer cut the sections of steel for the final model of the bracket in around 30 minutes. This means that the metal tube should be ordered in 1 piece. Creating the bracket cost the freelancers around 1.5 hours. This comes down to €75+€25.92=€100.92. This price can be lower when ordering 4 m of tube instead of 2 m, but this saves a mere 95 cents of material. The price can therefore also be considered as €100 per bracket.

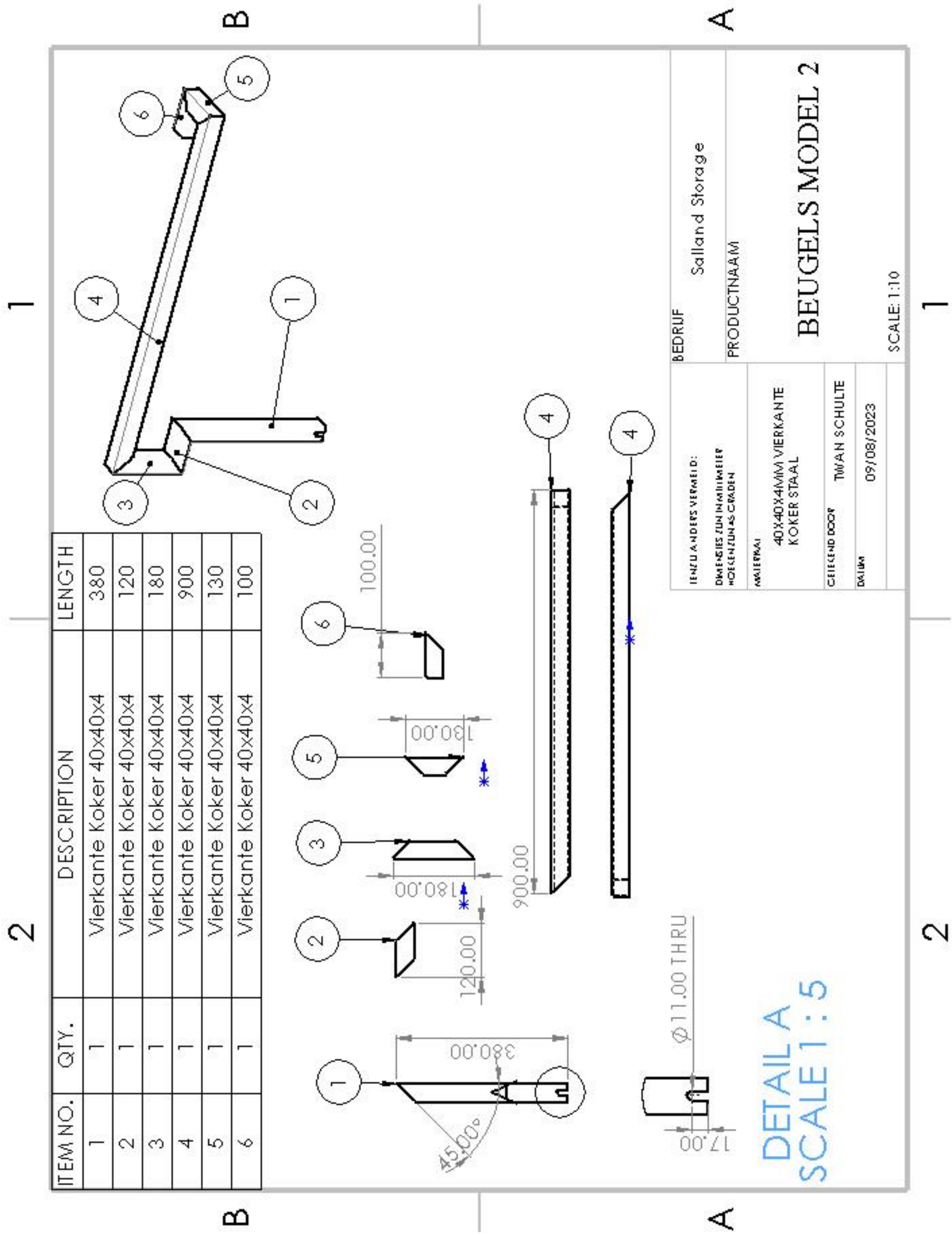
Appendix F: Bracket drawings

Note: these technical drawings were made in collaboration with the freelancer as there were no guidelines on drawings from the client. In the case of a mass-production, it is possible changes will have to be made to make the drawings according to official standards.

F.1: Technical Drawing Bracket L-L

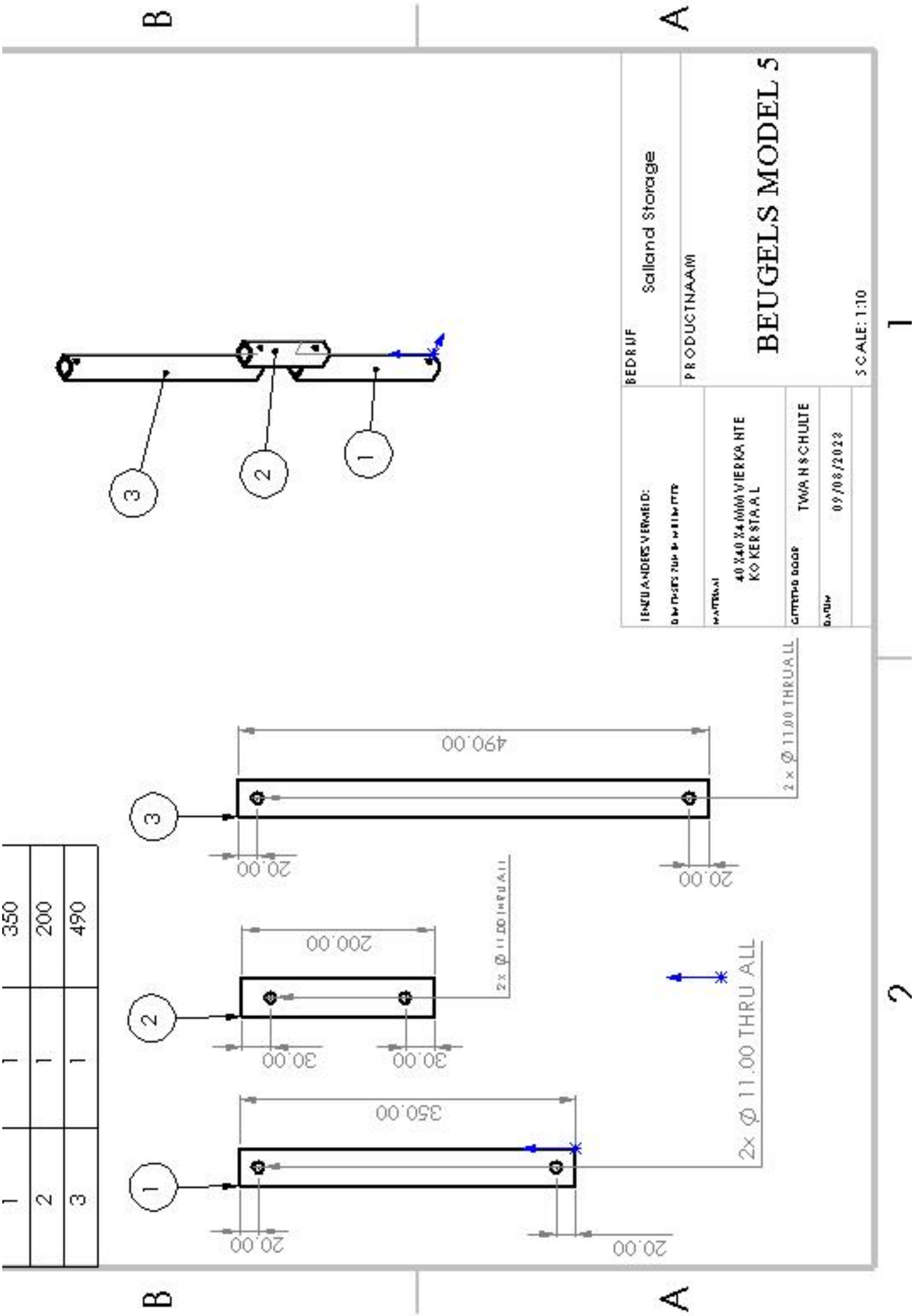


F.2: Technical drawing bracket 2-2



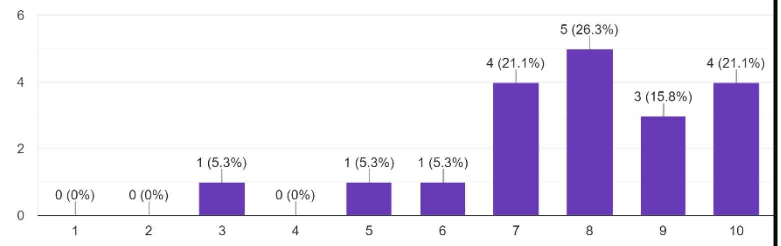
ITEM NO.	QTY.	DESCRIPTION	LENGTH
1	1	Vierkante Koker 40x40x4	380
2	1	Vierkante Koker 40x40x4	120
3	1	Vierkante Koker 40x40x4	180
4	1	Vierkante Koker 40x40x4	900
5	1	Vierkante Koker 40x40x4	130
6	1	Vierkante Koker 40x40x4	100

F.3: Technical drawing bracket 5-2

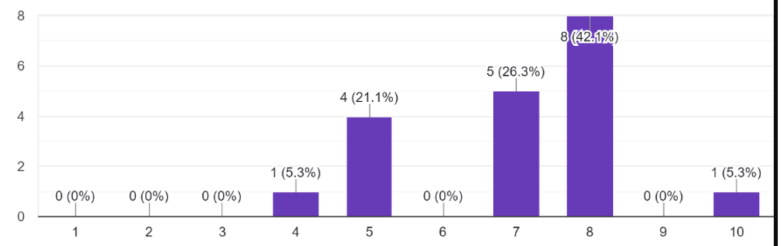


Appendix G: Experience compass evaluation

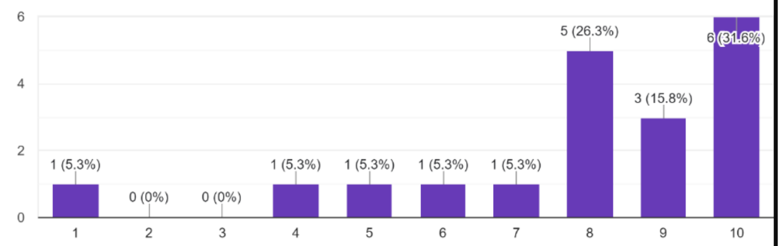
Hieronder ziet u een foto van een een metalen trap. Bepaal op een een schaal van 1-10 waar u denkt dat deze trap thuis zou horen. (1 = Enkel in een Speeltuin, 10 = Enkel in een industrieel bouwwerk)
19 responses



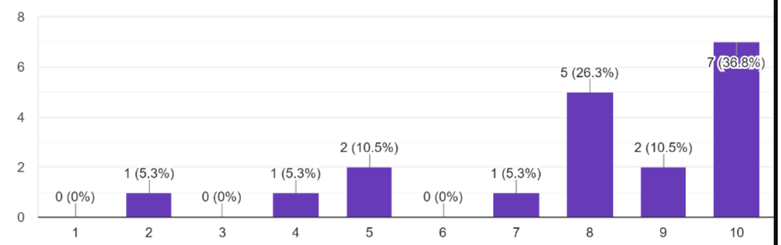
Hieronder ziet u dezelfde trap, met 2 aanpassingen. De onderkant is nu gesloten, en de trapleuning is gedeeltelijk bedekt met een zwarte plastic laag. ... Speeltuin, 10 = Enkel in een industrieel bouwwerk)
19 responses



Hieronder ziet u een foto van een een metalen brug. Bepaal op een een schaal van 1-10 waar u denkt dat deze brug thuis zou horen. (1 = Enkel i... Speeltuin, 10 = Enkel in een industrieel bouwwerk)
19 responses

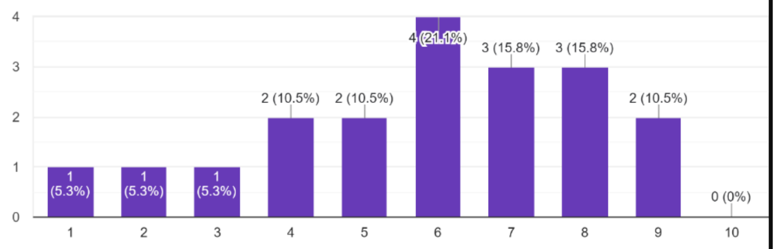


Hieronder ziet u een foto van een aangepaste metalen brug. Een zijkant is gesloten, en de uiteindes zijn afgerond met zwarte doppen. Bepaal op een een...eeltuin, 10 = Enkel in een industrieel bouwwerk)
19 responses



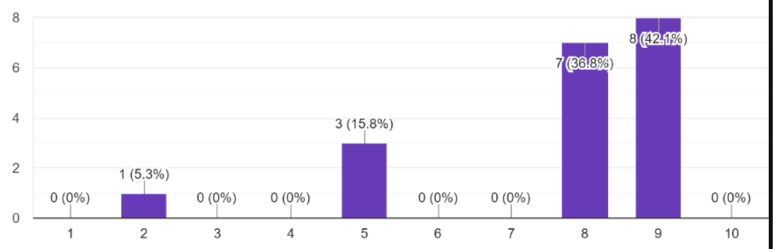
Hieronder ziet u weer een foto van een een metalen trap. De trap beweegt lichtelijk tijdens het traplopen. Bepaal op een een schaal van 1-10 welk ...ncomfortabel, 10 = Volledig veilig & Comfortabel)

19 responses



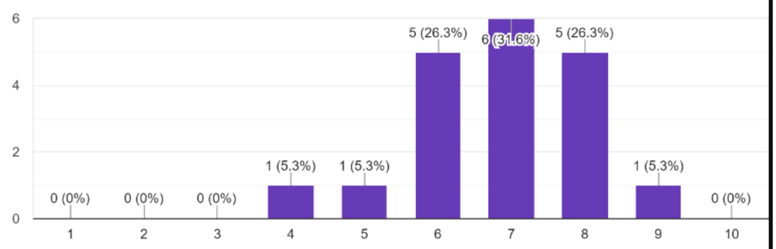
Hieronder ziet u dezelfde trap, met 2 aanpassingen. De onderkant is nu gesloten, en de trapleuning is gedeeltelijk bedekt met een zwarte plastic laag. ...oncomfortabel, 10 = Volledig veilig & Comfortabel)

19 responses



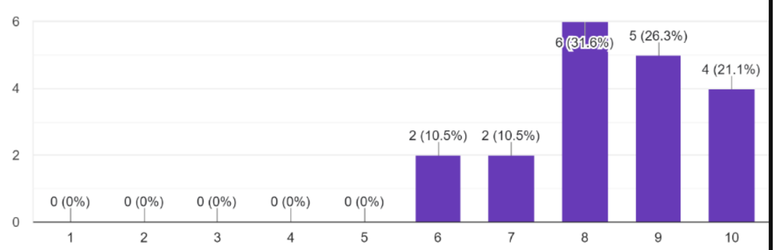
Hieronder ziet u weer een foto van een een metalen brug. De brug beweegt lichtelijk heen en weer tijdens gebruik. Bepaal op een een schaal van 1-10 ...ncomfortabel, 10 = Volledig veilig & Comfortabel)

19 responses



Hieronder ziet u weer een foto van een aangepaste metalen brug. Een zijkant is gesloten, en de uiteindes zijn afgerond met zwarte doppen. De bru...ncomfortabel, 10 = Volledig veilig & Comfortabel)

19 responses



Appendix H: Case study – Expense report

Category	Object	Cost	Amount of Units	Total Cost	Source
Bottom Layer Z-Boxes	Z-box (Model 2)	5,500	64	352,000	Client
	Z-box (Model 5)	6,000	20	120,000	Client
	Assembly & Placement	45	80	3,600	Client
Top Layer Z-boxes	Z-box (Model 2)	5,500	42	231,000	Client
	Z-box (Model 5)	6,000	14	84,000	Client
	Man Hours	45	50	2,250	Client
Stairs Assembly	Stairs	1,768	2	3,537	https://shop.easystairs.nl/stalen-trap-15-treden-sat-1000mm
	PVC Pipe	16	2	32	https://www.hornbach.nl/p/martens-pvc-buis-dikwandig-komo-4000-x-40-mm/4105945
	Wood Plank	17	4	68	www.karwei.nl/assortiment/hardhout-multiplex-gegrond-122x61-cm-dikte-3-6-mm/p/B560570
	L-bracket	10	1	10	https://www.staalvakman.nl/hoekprofiel-wgw-onbewerkt-staal-35x35x3-mm
	Man Hours	45	2	90	Client
Bridge Assembly	Bridge	3,108	3	9,324	https://shop.easystairs.nl/loopbrug-4000mm
	Billboard	300	3	900	https://www.drukwerkdeal.nl/nl/producten/buitenreclame/reclameborden-plaatmateriaal
	Round Endcaps	0	12	3	https://nl.aliexpress.com/i/32710070092.html?gatewayAdapt=glo2nld
	Man Hours	45	9	405	Client
Railing (Standard)	Beams	50	4	200	(300cm) https://www.metaalwinkelonline.nl/aluminium-rechthoekige-buis
	Billboard (350cmx129cm & 242cmx192cm)	195	4	780	https://www.drukwerkdeal.nl/nl/producten/buitenreclame/reclameborden-plaatmateriaal
	Man Hours	45	8	360	Client
Railing (Stairs)	Adapted L-bracket	50	2	100	Welding + Material
	Beams	20	4	80	(240cm) https://www.metaalwinkelonline.nl/aluminium-rechthoekige-buis
	Billboard (110cmx129cm)	87	4	349	https://www.drukwerkdeal.nl/nl/producten/buitenreclame/reclameborden-plaatmateriaal
	Man Hours	45	2	90	Client
Railing (Corner)	Beams	110	2	220	(850cm) https://www.metaalwinkelonline.nl/aluminium-rechthoekige-buis
	Billboard (500cmx129cm + 226cmx129cm)	467	4	1,868	https://www.drukwerkdeal.nl/nl/producten/buitenreclame/reclameborden-plaatmateriaal
	Beam Foot	21	1	21	
	Corner profile	50	2	100	https://www.metaalwinkel.nl/aluminium-vierkant-bouwsysteem-topclamp.html
	Man Hours	45	2	90	
Railing (Bridge)	Beams	80	12	960	Consultation with client (custom build)
	Billboard (145cmx29cm)	107	6	642	https://www.drukwerkdeal.nl/nl/producten/buitenreclame/reclameborden-plaatmateriaal
	Man Hours	45	2	90	
Walkway	Rubber Tiles (100x100x2.5)	35	506	17,457	https://www.rubbermagazijn.nl/rubber-terrastegel-zwart-100x100x2-5cm_zwart_12615.html
	Water Drainage	4	3163	11,577	Firm offer Client
	Man Hours	45	5	225	
Set of bracket L-L		46	84	3,864	Appendix E.2
Bracket 2-2		100	12	1,200	Appendix E.4
Bracket 5-2		25	4	100	Section 6.2.4
TOTAL				€ 932,350	

Appendix I: Bracket 5-2 testing

Near completion of this thesis, testing for bracket 5-2 also commenced. A few observations and problems arose, that will be explained here.

First of all, it should be noted that the upper Model 5 and the lower Model 2 were not in line with each other. This is due to the current setup of testing in Deventer, and this test should be repeated after the Z-boxes are lined up properly.

Problem	Solution
The bolts going through the bracket and into the Z-box were slightly too short.	The bolts were swapped out for threaded rods, giving more margin in the length.
The nuts could not be properly tightened due to the wrench not fitting into the steel beam	- Welding the nuts to the inside of the beam (*Future*) - Threading the holes (*Future*)
The length of the middle section was slightly too short	Testing different margins, lengthening the middle section

Figure 109 shows the installed bracket 5-2. Due to the Z-boxes not lining up, the threaded rod can still be seen here. In future tests, this will not be the case.

Figure 109 Bracket 5-2 test install