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Redesign and Implementationn of Design Improvement to Flood Protection System

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Preface

Writing a master thesis includes quite a lot of work, commitment and structure. When I started working with the AquaFence flood protection system in the pre-master thesis last autumn I had not imagined what kind of journey the last year would become. When allocating the amount of time a master thesis project requires, and working so focused, it is motivating how much you learn. Not only about the topic of study, but also about conveying a project, searching for literature and writing scientifically. Important knowledge that has not necessarily been taught in class during the five years at university.

My personal goal when I started working with this master thesis was that when I finished, I would be an expert in product development that is effective and efficient - that is economical, fast and considers all stakeholders, life phases and virtues of the product in a holistic perspective. When I in my coming engineering career will work on development projects, I can think back on this project and use the same approaches.

Being able to immerse myself into the field of product development and engineering design has been really exciting. When looking into literature, I understood how diverse and complex the world of product development techniques and methods is. I found numerous of methods that partly or wholly could fit as a framework for this thesis, but I couldn't use all of them. I also learned that thinking about new concepts and solving problems is quite easy, but there is a hard part following, getting down to details and trying to get things working. Engineering design is not just about following procedures - it's also a lot of brainwork. I also experienced that when working on projects like this, teamwork is preferred. When working alone as I did, you tend to get stuck in a track, and you don't have anyone to discuss with.

To follow the development process from start to the end, and seeing my ideas realised has been really interesting. The project and the report has been very comprehensive, so it has sometimes been difficult to have an overview, even though I have written and done everything myself. There is always something that could have been done better, but I am nevertheless proud of my work, including the process, the report and the results.

At the end, I would like to thank Edijs Jumburgs, Managing director of AquaFence Latvia, for outstanding hospitality during my visits in Latvia and for providing relevant product information and technical feedback. I would also like to thank AquaFence' CEO Fred Dahl and NTNU Professor Torgeir Welo for giving me the opportunity to cooperate with AquaFence. The last person I would like to give a sincere thanks to, is Thea Caroline Wang (the Norwegian Water Resources and Energy Directorate) for proof reading, giving me useful feedback and for keeping me motivated.

When I now write this last sentence, five years of mechanical engineering studies at the Norwegian University of Science and Technology (NTNU) are over. It has been a good time, but I am really looking forward to start a new era using my engineering knowledge in new situations.

Henrik Vagle Dalsgaard Trondheim, 10 June 2015

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Abstract – English version

The purpose with this thesis is to assist AquaFence in keeping their competitive edge within the mobile flood protection system market. The business objective is to develop a redesigned product that provides additional value. This is done by first analysing the current system and then basing the development of the new system on that. The value analysis methodology and the IPM model for engineering design are used as a framework in the entire thesis. Design for X is also applied to ensure that the development is done in a holistic perspective.

The thesis does not cover the entire flood protection system, but a sub-system of that, namely the system of connecting two panels together.

The analysis part of the current system is performed as a case study, and includes a review of stakeholders, user situations, problems and issues, installation time, usability, a functional analysis, and also a synthesis of user demand specifications and product requirement specifications.

The development of the new design is performed as an action research and uses the inputs collected in the case study as a fundament. A creative concept generation process provides 30 solutions that are evaluated against Design for X criteria. One concept is selected using an evaluation matrix and the design is thereafter elaborated on. The design is described in detail, verified, validated and tested.

The test results show a reduction in installation time by 75 % and an increase in system usability by 150 %. The results are furthermore discussed in the aspect of how this and the design changes can lead to increased value for AquaFence and for the customers. Based on the results and the discussion, it is recommended to implement the new design. The thesis ends by proposing further work that is needed to successfully implement and benefit from the new system.

Keywords: value engineering, user experience, design for X, engineering design, product development, flood protection system, design improvement, IPM

Sammendrag – Norwegian version

Hensikten med denne oppgaven er å bistå AquaFence i å beholde deres konkurransefortrinn i markedet for mobile flomvernsystem. Målet er å utvikle et redesignet produkt som gir økt verdi. Dette gjøres ved å først analysere dagens system for så å basere utviklingen på det. Metodikk for verdianalyse og IPM-modellen for produktutvikling er brukt som et rammeverk i hele oppgaven. Design for X er også brukt for å sikre at utviklingen er gjort i et holistisk perspektiv.

Oppgaven tar ikke for seg det fullstendige flomvernsystemet, men kun en liten del av det, nemlig systemet for å koble sammen to flomvernselementer.

Analysen av dagens system er gjennomført som et casestudie, og inkluderer en gjennomgang av interessenter, brukssituasjoner, problemer og utfordringer, installasjonstid, brukervennlighet, en funksjonsanalyse samt en syntese av brukerkravspesifikasjoner og produktkravspesifikasjoner.

Utviklingen av det nye systemet er gjennomført i form av aksjonsforskning og bruker innsamlet input fra casestudiet som fundament. En kreativ konseptgenereringsprosess kommer opp med 30 konsept som så blir vurdert mot design for X-kriterier. Ett konsept velges ved hjelp av en evalueringsmatrise og blir jobbet videre med. Den nye løsningen beskrives i detalj, verifiseres, valideres og testes.

Testresultatene viser en betydelig reduksjon på 75 % i installasjonstid og en økning på 150 % for systemets brukervennlighet. Resultatene er videre diskutert i forhold til hvordan dette og de aktuelle endringene i designet påvirker verdien for AquaFence og deres kunder. Basert på resultatene og diskusjonen så anbefales det at det nye designet implementeres. Oppgaven avsluttes med forslag til videre arbeid som er nødvendig for en suksessrik implementering og utnytting av det nye systemet.

Stikkord: verdianalyse, brukeropplevelse, design for X, produktutvikling, produktforbedring, flomvernsystem.

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1 Introduction

1.1 Background

AquaFence is a Norwegian engineering company developing, producing and selling a mobile flood protection system. They have been in the international market the last ten years, obtained the highest level of certification for flood protection barriers, and claim to have the world's leading mobile flood protection system.

The flood protection system is module based in a way that an unlimited number of modules, or panels, are placed after each other to form a barrier. The panels each size from 1.2 - 2.1 meters in length and 1.2 - 2.4 meters in height, and the barrier will lead or hinder the water according to the situation. The flood barrier is usually installed ahead of an expected flood event as an urgent measure when time and resources are limited. Proper functioning of the flood protection system is pivotal. Consequently, quality is important, and since the initial cost is high, the perceived customer value needs to be high.

Dealing with flood protection measures is not only a matter of business. During the last four decades flood has become a rising threat, and the number of reported flood related disasters on a global level has increased from a few hundred in 1971 - 1980, to nearly 2000 in 2001 - 2010. 44 % of all reported natural disasters in the period 1970 - 2012 were due to flood (World Meterological Organization 2014). It is therefore necessary that commercial forces use technology and knowledge to provide the society with innovative and high quality solutions.

The frequency of flood events is increasing and the competition among flood protection providers is growing correspondingly. In order for AquaFence to keep their competitive advantage, it is essential to further develop today's system. To keep their leading position nationally and internationally based on Norwegian engineering competence, research and innovation is needed.

Governments and property owners around the world buy the product, but the product is not without issues and challenges. AquaFence has started a research and development collaboration with the Norwegian University of Science and Technology (NTNU) and aim to improve their flood protection system. The collaboration is twofold. One part of it is to continuously improve today's solution. The other part is to develop an entirely new system for the future, called Flood Protection System 2020. The intention is to use experiences and learnings from the continuous improvement processes for the development of the 2020 system. The thesis is part of the continuous improvement.

1.2 Objectives

During autumn 2014 a pre-master project was carried out where the objective was to find out which challenges within AquaFence' flood protection system would be the most attractive to improve. An attractive challenge was defined as a challenge where the potential for increased value was high for both AquaFence and the customer. Several areas of improvement were identified in which the value could be increased, either through costs reductions or through user experience enhancement.

One of the improvement areas that received a high score regarding attractiveness of improvement was the system and method of connecting the flood protection panels to each other during the installation phase. The current system proved to be time consuming, not very intuitive and also required specialised installation equipment. Since these issues were critical for the user experience and for the functionality of the product, the potential for increased value was huge.

It was decided to elaborate on that area, and this thesis will focus on improving the way the panels are connected to each other. The work will not encompass the entire flood protection system, but a limited fragment of it, namely the connection system. The main objectives will consequently be to:

I. Contribute to the research and development collaboration between AquaFence and NTNU by providing in-depth knowledge and analysis of the current connection system.
II. Improve the connection system from a holistic perspective using design for X strategies.
III. Develop a redesign for the connection system that provides additional value for AquaFence, customers and users.
IV. Reduce the installation time for the connection system.

1.3 Scope

In order to improve and redesign the particular area to something where the quality is ensured and the value is increased, a systematic and structured approach is needed. This thesis consist of several chapters, including an introduction, a theory chapter, a case study, an action research, discussion, conclusion, reference list and appendices.

CHAPTER 1 is an introduction to the thesis and describes the background, the objectives and the scope of the thesis.

CHAPTER 2 is a theory chapter and introduces several theories in order to understand the methodology and terms used. The methodologies of value analysis job plan, the IPM-model for product development and design for X are introduced and are used as framework for the thesis. Table 1 visualises the scope and shows how these methodologies apply to the content in the thesis. Also a test procedure for validation of performance is designed.

CHAPTER 3 takes the form of a case study describing the current system in detail. Several aspects are analysed, including the history of AquaFence, functionality, stakeholders, user situations, related problems and installation procedure. These aspects, together with a functional analysis, form the basis for a synthesis of demands and requirements.

CHAPTER 4 is an action research trying to develop and test a new solution for the system. The development is based on inputs from the case study, design for X and techniques from the IPM-model. One concept is selected using an evaluation matrix and further elaborated on. The new system is built, tested through verification and validation, and compared with today’s solution.

In CHAPTER 5 the procedure, the methodology and all the results are discussed. The improvements are quantified and discussed in terms of relevance and value for various stakeholders. Also, limitations and weaknesses are highlighted.

CHAPTER 6 provides an executive summary, comprising findings, conclusions and recommendations. A review of the objectives and proposals for further work is also provided.

Value Analysis	Job plan phases*	Section		IPM phase	
Pre-workshop	Preparation	1 - Introduction		Phase 1 – Vision	
		2 - Theory			
Value Workshop	Phase I – Information	3.1 - History of AquaFence			Case study
		3.2 - Functionality			
		3.3 - A systematic breakdown of the flood protection system			
		3.4 - Stakeholders		Phase 2 – Demand and technology analysis	
		3.5 - User situation			
		3.6 - Problems and issues			
		3.7 - Installation and installation time			
	Phase II – Functional analysis	3.8 - Functional analysis			
		3.9 - Synthesis of demands and requirements	DfX Applied	Phase 2 – Demand and technology analysis	
	Phase III – Creative	4.1 - Concept development		Phase 3 – concept development	Action research
	Phase IV – Evaluation	4.2 - Concept evaluation and selection			
	Phase V - Development	4.3 - Presentation of the new system		Phase 4 – Structure and design	
		4.4 - Verification			
		5 - Discussion			
		6 - Conclusion			
Post workshop	Implementation	Out of scope		Phase 5 – Preparation for production	

Table 1: Visualisation and organisation of the scope

**) The job plan phase VI – presentation, is not included in this table because the entire report constitutes this phase.*

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2 Theory

This chapter describes relevant theories that are used in the thesis. The theories are used as background knowledge in decision making, as direct methodology and as a framework of thinking and working. Also, relevant terms are defined in this chapter.

2.1 User experience

User experience is a person's perception and responses resulting from the use of a product, system or service (ISO 9241-210:2010). Furthermore, the user experience premises three main characteristics which include that a user is involved, that a user is interacting with a product, system or service, and that the user's experience actually is of interest and can be observed or measured (Tullis and Albert 2013).

The difference between user experience and usability is not well defined, but some distinctions can be made. *Usability* is usually thought of as the ability of the user to use a product to carry out a task successfully. User experience on the other hand takes a broader view, looking at the individual's entire interaction with the product, as well as the thoughts, feelings, and perceptions (Tullis and Albert 2013).

The ISO standard 9241-210:2010 defines user experience in more detail as:

- User experience includes all the user's emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during and after use.
- User experience is a consequence of brand image, presentation, functionality, system performance, the user's internal and physical state resulting from prior experiences, attitudes, skills and personality, and the context of use.

Most aspects of a product will influence the user's experience either directly or indirectly, and the user experience is not restricted to time, place or any specific attributes of a product.

2.2 Analysing and improving value

This section defines value, describes how value can be increased, and relates value to competitive advantage. Thereafter a methodology for systematically analysing and increasing value is introduced.

VALUE

The *value* of a product will be interpreted in different ways by different stakeholders having ideas of what is valuable for them. The common characteristic of product value is a high level of performance, capability and emotional appeal relative to its cost, and can be expressed as maximising the function of a product relative to its cost, Eq. 1 (Crow 2002).

$$Value = \frac{Performance + Capability}{Cost} \quad (1)$$

Weinstein and Johnsons (1999, cited by Browning 2003) has another definition of value, Eq. 2, saying that value is the ratio of perceived benefits to perceived price, measured relative to competing products or services.

$$Value = \frac{Perceived\ Benefits}{Perceived\ Price} \quad (2)$$

A third definition was elaborated by Park (1998) after reviewing the work on value equations from several authors. Despite different wording, he noticed that they all agreed that value is the ratio between function, described as a goal, need, want or objective, and cost, described as currency, effort, resources. He defined it as Eq. 3:

$$Value = \frac{Function}{Cost} \quad (3)$$

In this case function is defined as what the product does for the customer, and could also in many situations be considered to be product performance. In the end it is about what the person or unit that perceives or experiences the value gets in return after exchanging the appropriate assets.

By recalling the ISO definitions of user experience from the previous section, it is seen that emotions, perceptions, functionality and performance, which are all parts of the previous definitions of value, are also a part of user experience. Consequently Eq. 1 - 3 can be rewritten as:

$$Value = \frac{User\ Experience}{Cost} \quad (4)$$

Value is not a matter of minimising cost. In some cases the value of a product can be increased by both increasing cost and its function or user experience, as long as the added function or experience increases more than the added cost (Crow 2002). A decrease in cost simultaneously as an increase in function and user experience will hence add the most value.

INCREASING VALUE

From a company perspective, increasing value through reducing the production cost makes sense because reduced cost will return a higher margin. A higher margin can thereafter lead to cost leadership. Increasing value through enhancing the user experience also makes sense because an enhanced user experience will improve customer loyalty (Garrett 2006). Since the actual product is the company's one touch point with which the user is likely to spend the most time, the user experience needs to be improved through the actual product (Garrett 2006). Enhanced user experience can then lead to differentiation because the product is improved and differentiated.

From a customer's perspective, the value does not increase if the production costs are reduced, unless the reduced production cost leads to reduced market prices. Increasing value through enhancing the user experience makes sense because the customer always wants a better product at the same price (Manikutty 2011).

COMPETITIVE ADVANTAGE

Competitive advantage is a business concept that describes how an organization can outperform its competitors. There are two basic types of competitive advantage, cost leadership and differentiation.

Cost leadership aims to offer products or services at the lowest cost in the industry. Cost leadership is different from price leadership where the product price, rather than production cost, is the lowest in the market (Porter 1998).

Differentiation aims to provide uniqueness at something that is valuable for the customers. To provide products or experiences that competitors are not yet offering or are unable to offer, is an example of that. A differentiation strategy is appropriate in markets where customers are less price-sensitive (Porter 1998).

By applying both cost leadership and differentiation, a company can aim for a hybrid strategy for competitive advantage (Baroto et al. 2012).

VALUE ANALYSIS

To systematically increase the value of a product, process or project, a value study using value methodology can be carried out. SAVE International has published the *Value Methodology Standard* (SAVE International 2007) that provides a practical guide for applying the principles of the value methodology in a consistent manner, namely to increase the value through the analysis of its functions.

A value study generally comprises of three stages where the second stage consist of a six phase job plan:

- *Pre-workshop - Preparation.* A clear understanding of what the client needs to have addressed, what the strategic priorities are, and how improvements will increase organizational value, are mapped.
- *Value Workshop* - Execution of the six phase job plan
    - *Information phase.* A thorough understanding of the problem, objective, context and current conditions of the product is established. The goals of the study are identified.
    - *Functional analysis phase.* Functions are reviewed and analysed to determine the need of improvement, elimination, or creation to meet the product's goals. Functional Analysis is the foundation in the value methodology and is the key activity that differentiates it from other improvement practices. Functional analysis is described more in-depth below.
    - *Creative phase.* Creative techniques are employed to identify other ways to perform the product's functions. The goal is to generate as many ideas as possible based on the project needs or functions.
    - *Evaluation phase.* Ideas generated in the creative phase are systematically evaluated, screened and short-listed based on their potential to add value.
    - *Development phase.* Ideas selected in the evaluation phase is explored in detail and developed into proposals with a sufficient level of documentation.
    - *Presentation phase.* The proposal that has been generated and that demonstrates a better value than the original solution, is presented through a report and a presentation.
- *Post-workshop - Documentation and implementation.* The accepted value alternatives are implemented and the benefits foreseen by the value study is realised.

The value methodology can be applied to a wide variety of applications, including industrial or consumer products, construction projects, manufacturing processes, business procedures, services, and business plans (SAVE International 2007).

FUNCTIONAL ANALYSIS

The *functional analysis* is perhaps the most important phase in a value analysis (Crow 2002). To understand what a functional analysis is, it is necessary to define what a function is.

Functions are abstractions of what a product should do and are often described as verb-noun combinations (Jelierse and van der Vegte 2008). For example; one function of a nutcracker is to hold nut.

The purpose of the functional analysis is to provide a comprehensive understanding of the product, the product's functions, sub functions and preconditions. It focuses on what the product does or must do rather than what it is (SAVE International 2007). It also identifies excessive or redundant functions that lead to higher cost (Crow 2002).

The starting point of an analysis may be a hierarchical function tree based on an existing solution of the design problem, including all functions and sub. The principle is to first specify what the product does, and then to infer what the parts, which have not yet been developed, should do (Jelierse and van der Vegte 2008).

The strength of functional analysis lies in the possibility of creating and comparing at an abstract level. Since functions are abstractions of what a product should do, the designer is forced to think about the product in an abstract way. This abstract thinking stimulates creativity, and prevents immediately elaboration on the first idea that comes to mind, which may not be the best (Jelierse and van der Vegte 2008). The focus is moved away from expected solutions and is rather on the required performances and needs. The more abstractly a function can be defined, the more possible solutions will be revealed (Crow 2002).

2.3 Design for X

Design for X, DfX or Design for eXcellence is generally regarded as a systemic and proactive way of designing products to optimise total benefits over the whole product life span and involves different methodologies for product design and optimisation (Ciechanowski et al. 2007). DfX provides systematic approaches for analysing design from a spectrum of perspectives in an integrated way. Most DfX tools are usually not considered as design systems in the way that they do not make design decisions. Instead they evaluate design decisions from a specific point of view (Huang 1996).

There are two views on the meaning of the X in DfX. The first one suggests that the X is used as a variable term that can be, for example, manufacturability, transportability, reliability, usability or disposability. The other view is that Design for eXcellence suggests using as many 'Design for' methods as suitable to achieve excellence. Both meanings should be applied (Tarr 2007).

The DfX toolbox has expanded rapidly the last 25 years, and counts many hundred different tools (Huang 1996). There are several papers (Gatenby and Foo 1990, Huang 1996, Meerkamm and Koch 2005, Bauer and Paetzold 2006, Lindemann 2007, Holt and Barnes 2009, Dombrowski et al. 2014) that suggest lists of different X's that could be considered in the design process. None of these lists are exhaustive and none of them will match a specific product in a specific marked perfectly. For every project one needs to find and select which X's are suitable and applicable in that specific case.

Holt and Barnes (2009) divided all the DfX tools into one category related to the different life phases of the product and one related to qualitative attributes or virtues that the product should possess. A selection of relevant DfX approaches are listed in Table 2, and further described in the following sections.

DfX virtue	
Quality	DfQ
Cost	DfC
Environment	DfE
Safety	DfS
Maintainability	DfMt
Reliability	DfR

DfX life phase	
Manufacturability	DfM
Assemblability	DfA
Transportability	DfT
Usability	DfU
Recyclability	DfRc

Table 2: Different DfX approaches used in this thesis.

When looking into the different X's in the following sections, it will be clear that a lot of the DfX virtues and DfX life phases are interconnected and dependent on each other.

2.3.1 Design for quality

Quality is generally defined as "*compliance with requirements*", which means the degree to which the characteristics of a product meets the given requirements (Biggioggero and Rovida 1996). In addition to being concerned with meeting and exceeding the customer's requirements, *design for quality* ensures that the product is robust to variations in manufacturing, that potential errors are identified and eliminated, and that durability, reliability and performance is improved (Kuo et al. 2001).

2.3.2 Design for cost

The purpose of *design for cost* is to reduce and minimise cost through the entire lifecycle (Holt and Barnes 2009). Minimising cost can be done by minimising different cost drivers. Huang (1996) lists over 60 typical cost drivers in a table (Appendix 8.4) where he divides them into cost drivers related to product, process and resources.

Examples of cost reducing measures can be to simplify the structure, reduce the number of parts and processes, minimise the precision, use of standard parts, eliminate reworks and minimise the time used.

According to Allting (1993, cited in Asiedu and Gu 1998), the costs drivers will be assigned to the company, to the customer or to the society.

2.3.3 Design for environment

There is a growing concern about damage to the environment and the purpose of *design for environment* is to reduce the environmental impact. It embraces design for disassembly, design for recycling, lifecycle costing and sustainable design (Holt and Barnes 2009)

Bevilacqua et al. (2012) suggest different issues to address and guidelines on how to realise them in Table 3.

Optimisation of initial life-time	High reliability, durability and easy maintenance and repair
Selection of low-impact materials	Use of recycled, recyclable, renewable, non-hazardous materials
Reduction of material	Reduction in weight and transport volume
Optimisation of production techniques	Fewer production processes, low/clean energy consumption and low generation of waste
Reduction of the environmental impact in the user stage	Low energy consumption and few consumables needed during use
Efficient distribution system	Less/clean packaging and efficient transport mode
Optimisation of end-of-life system	Reuse of product, remanufacturing and recycling of materials

Table 3: Environmental issues to address and guidelines on how to realise them

Also others have made guidelines for merging environmental aspects into product development, such as Luttropp and Lagerstedt (2006) with their *Ten Golden Rules*.

2.3.4 Design for Safety

In order to be in line with laws and regulations, to avoid complaints and impaired reputation, and to not harm people that are in contact with the product, a *design for safety* approach should be applied.

Safety includes identifying hazards and finding out what can be done to eliminate, reduce, or control them (Rausand and Utne 2009). Hazards can be related to different forms of energy seen in Table 4.

Gravity	Falling objects, collapses, body tripping
Motion	An object in motion like a vehicle, flowing water, wind
Mechanical	Rotating equipment, motors, compressed spring
Electrical	Presence and flow of electrical charge
Pressure	Pneumatic or hydraulic equipment
Temperature	Flames, hot/cold surfaces, liquids/gasses
Chemical	Chemicals that can create a physical or health hazard to people.
Biological	Living organisms that can present a hazard
Radiation	Energy emitted from radioactive elements
Sound	Equipment noise, vibration, high-pressure release

Table 4: Different forms of hazards (Chevron Corporation 2008)

Elimination of these hazards will increase the product and process safety, and this should be considered in every life cycle phase to avoid harm to all people, directly or indirectly, associated with the product (Rausand and Utne 2009).

2.3.5 Design for maintainability

When *designing for maintainability* one assures that the product can be maintained throughout its life-cycle at reasonable expenses without difficulty (Kuo et al. 2001). Both Kuo et al. and Pahl et al. (2007) suggest different guidelines to improve the maintainability and include among others:

- It should be easy to detect and isolate failures.
- It should be possible to remove broken parts without interrupting with critical functions and without removing functional units.

- It should allow easy access and exchange for all replaceable parts.
- The dimensional limits should be concerned so that replaceable units can be transported to a repair shop.
- The need for special tools should be minimised.
- Sharp edges that could cause injury to personnel should be avoided.

2.3.6 Design for reliability

Reliability is the ability of a product to perform its function over an intended period under defined operating conditions without failing (Kuo et al. 2001), and the purpose with *design for reliability* is then to reduce the failure rate (Holt and Barnes 2009).

The Warwick Manufacturing Group (2007) has made a list of guidelines that can improve the reliability of the design by:

- Reducing the failure rate
- Redundancy
- Robustness by making the design insensitive to all uncontrollable sources of variation
- Reducing design complexity
- Maximising use of standard parts
- Determining root causes of defects, not symptoms
- Controlling the significant and critical factors
- Carrying out preventive maintenance

2.3.7 Design for manufacturability and assembly

Designs that are constructed with a focus on being easy to manufacture and assemble are much more likely to avoid redesign (Warwick Manufacturing Group 2007). Failing to consider manufacturability and assembly in design can result in products that are either fundamentally impossible to make or more expensive than they need to be (Holt and Barnes 2009).

Edwards (2002) gathered and proposed a number of guideline for manufacturability and assembly, of which some are provided here.

Design for manufacturability:

- Favours objects with planes at right angles to each other
- Avoids unnecessarily tight tolerances.
- Designs the component so that it can be machined with a minimum number of tools and with standard tools.
- Selects materials that machines most readily.
- Minimises the number and duration of required machining operation.
- Inside radii on bends should not be less than the thickness of the metal.
- Avoids the use of undercuts where possible.

Design for assembly:

- Makes symmetrical components
- Standardises and reduces the number of materials, number of fixing types, components, assemblies and movements.
- Eliminates high precision fits whenever possible.
- Removes sharp corners from components so that they are guided into their correct position during assembly.

- Introduces guides and tapers which directly facilitate assembly
- Avoids expensive and time consuming fastening operations

One important thing to consider is that products designed for manufacturability and assemblability tend to have a fewer but more complex components, making maintenance and upgrading difficult.

2.3.8 Design for transportability

Transportation costs represent the most important element in logistics costs for most firms. An effective *design for transportability* creates greater economies of scale and reduces the price of goods and services. Transportability is desirable because it utilises distribution and transportation resources (Dowlatshahi 1996).

The military standard MIL-STD13 19A DOD (as cited in Dowlatshahi 1996) identifies the following design characteristics that affect transportability:

- Properties (width, height, length, centre of gravity)
- Dynamic limitations (acceleration, vibration, deflection, leaking)
- Environmental limitations (temperature, pressure, humidity)
- Hazardous effects (radiation, explosives, electrostatic, personnel safety)

If these characteristics are optimised, the stakeholders storing the product will also benefit from the design.

2.3.9 Design for usability

Usability is about the easiness of use and how effectively, efficiently and satisfactorily a user can interact with a product. In more details that is about:

Intuitive design	A very easy understanding of the structure and the functions
Efficiency of use	How much physical effort is needed
Effectiveness of use	How fast an experienced user can accomplish the tasks
Ease of learning	How fast a user who has never seen the user interface before can accomplish basic tasks
Memorability	After using the product once, if a user can remember enough to use it effectively in the future
Error frequency and severity	How often users make errors while using the system, how serious the errors are, and how users recover from the errors

Table 5: Factors of usability. Adapted from (Usability.gov 2013b)

In addition, safety is a criteria for usability (Mital et al. 2014).

2.3.10 Design for recyclability

More and more manufacturers will be responsible for recovering products at the end of their useful life (Huang 1996). This is to deal with the problem of millions of tons of landfill and of a planet with limited natural resources (Mital et al. 2014). Either if the producer takes back the product, or if the customer handles the disposal itself, there will be a benefit in having a product that is simple and cheap to recycle.

Pahl et al. (2007) suggest these guidelines to help reduce the cost of recycling:

- Disassembly-friendly construction structures
- Disassembly-friendly interfaces

- Only use materials that is possible to recycle
- If use is absolutely necessary, materials that can be dangerous to humans and the environment during reprocessing should always be easy to separate
- High value materials should be easy to separate.
- Minimise number of parts.

2.4 The relationship between value and DfX

Value can be defined as the ratio of user experience to cost (Eq. 4). Reduced cost, enhanced user experience, or both, will lead to increased value. DfX is defined as a set of systematic approaches for analysing design from a spectrum of perspectives (Huang 1996).

Design for maintainability is one out of many DfX aspects (Lindemann 2007), and assures that a product can be maintained throughout its life-cycle at reasonable expenses without difficulty (Kuo et al. 2001). Kuo suggests that in a product designed for maintainability, it should be easy to detect and isolate failures, and broken parts should be easy to remove without interrupting critical functions. Reliability is the ability of a product to perform its function over an intended period without failing. By designing for maintainability, also design for reliability is enabled (Kuo et al. 2001). Reliability further leads to quality since quality of many products depends upon their reliability. Failures are perceived by many users as an indication of poor quality (Clarkson and Eckert 2005). Design for quality ensures that the product is robust to variations in manufacturing, that potential errors are identified and eliminated, and that performance is improved (Kuo et al. 2001). A high level of performance is a common characteristic of product value (Crow 2002).

Following this logical reasoning, design for maintainability may lead to increased value. In the same way other DfX aspects relate to each other and to value. Based on the theory sections of user experience, value and DfX, a relationship map Figure 1 is compiled to show some possible causes and effects of different DfX and value.

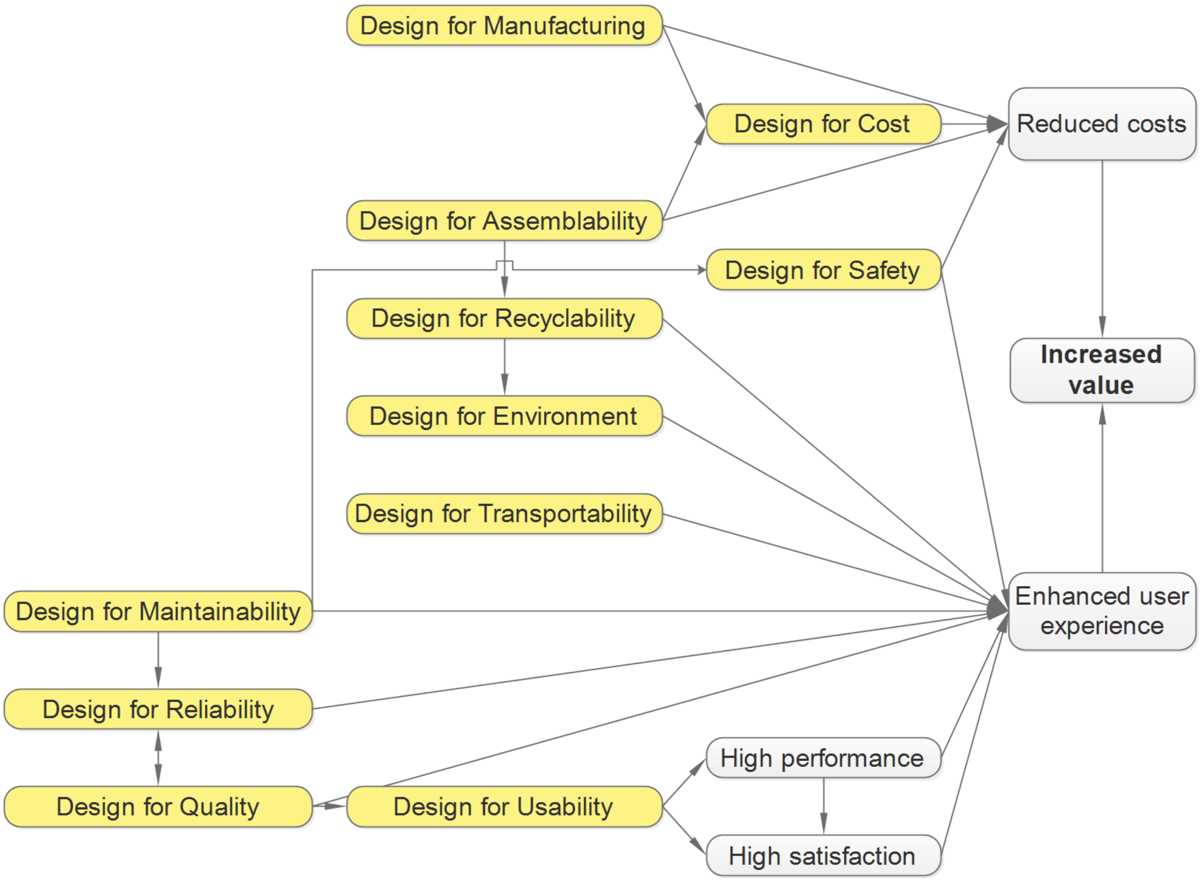

*Figure 1: The relationship between the different DfX and how they collectively contribute in increasing the value.**

**) This figure has no citation since it is developed during the work with this thesis.*

2.5 Systems theory

When describing and improving a system it is important to understand what a system is and to have some terminology to use.

A *system* is an assemblage or combination of functionally related elements or parts forming a unitary whole (Blanchard 2011), organised to achieve one or more stated purposes (ISO 15288:2008). The *performance of a system* is determined by the performance of the parts and their interactions, and the performance of a system is therefore not related to how parts perform separately. Performance is the product of a systems interactions, not the sum of its parts (Saha 2013). The relationship between cause and effect in a system is not always easy to detect since delayed reactions causes increasing complexity and inaccuracy. Despite this, minor changes can lead to major results. A change in any element of a system effects the whole and can be amplified by other elements or subsystems (Haines 2006).

There are several terms related to systems, and some common relevant terms are provided below.

Sub-system is a system hierarchically placed under a *parent system* which it is a part of. A system may have several sub-systems (Baylin 1990).

System element is a member of a set of elements that constitutes a system and can be either physical or abstract (ISO 15288:2008).

Interaction. System elements can interact and with each other, with other systems or with the environment. An interaction is a situation where a change in one element induces a change in another (Kühn 1974, cited by Walonick 1993). This interaction has two components: input, what enters an element from the outside, and output, what is left after the interaction. If the elements did not interact, the whole would not be more than the sum of its components (Heylighen 1998).

System of interest is the system whose life cycle is under consideration (ISO 15288:2008).

Enabling system is a system which complements the system of interest during its life cycle. The contribution from the enabling system is not necessarily made directly to the function or during the operation phase of the system of interest (International Council on Systems Engineering 2012).

System boundary. A distinction made by an observer which indicates the difference between a considered system and its environment (Checkland 1999).

Environment. The surroundings, either natural or synthetic, in which the system of interest is developed, produced, utilised, supported or retired (International Council on Systems Engineering 2012).

System elements, interactions, boundary and environment are visualised in Figure 2.

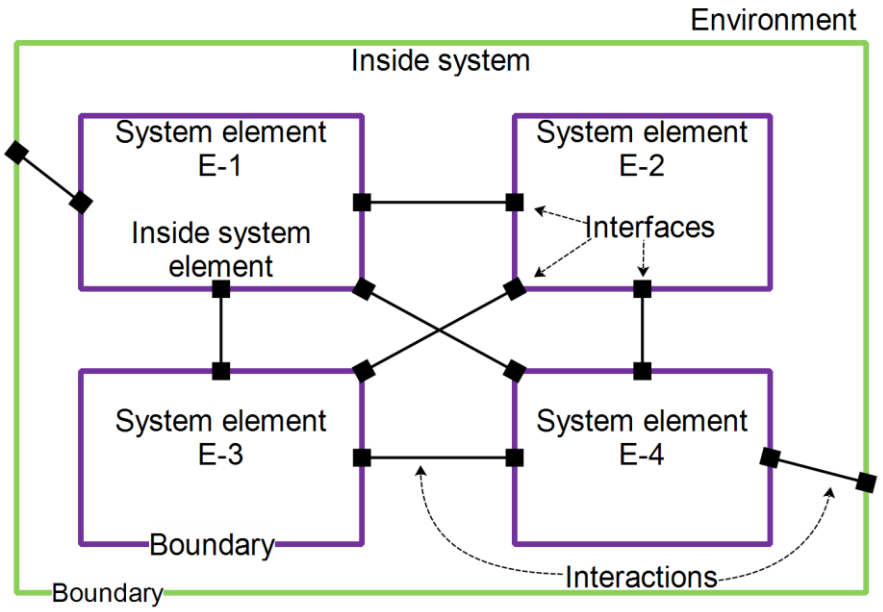

Figure 2: Visualisation of system elements (Haskins 2014)

Decomposition and aggregation of system, sub-systems and system elements are visualised in Figure 3.

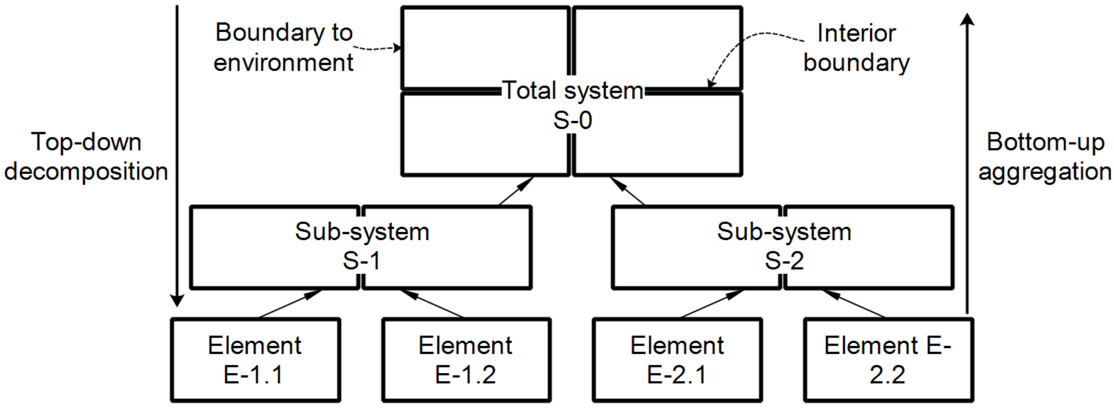

Figure 3: System decomposition and aggregation (Haskins 2014)

2.6 Product development methodology - the IPM model

There are several ways and methods to develop a new or improve an existing product. The purpose of a methodology is to give the developer models, procedures, tools and strategies in the product development work, and in that way increase the possibility of creating a good product. One of these methodologies is developed at Department of Engineering Design and Materials (Institutt for produktutvikling og materialer - IPM) at the Norwegian University of Science and Technology and is called the *IPM model*. This section will describe this model, and the content herein is entirely based on Grave's (2013) book about product modelling and product development.

The IPM model is a milestone oriented process divided into five phases, where the product gradually is more and more detailed, all the way from a marketing potential to detailed production description. Each phase ends up in a milestone with a deliverable, and decisions are made. Depending on the circumstances and characteristics of the project, the different phases and their content will vary. A generic overview of the milestones, the phases and what the phases could contain is shown in Figure 4. At a milestone, it is decided whether the project can continue to the next phase, if more work in the current phase is needed, or if the project should be terminated.

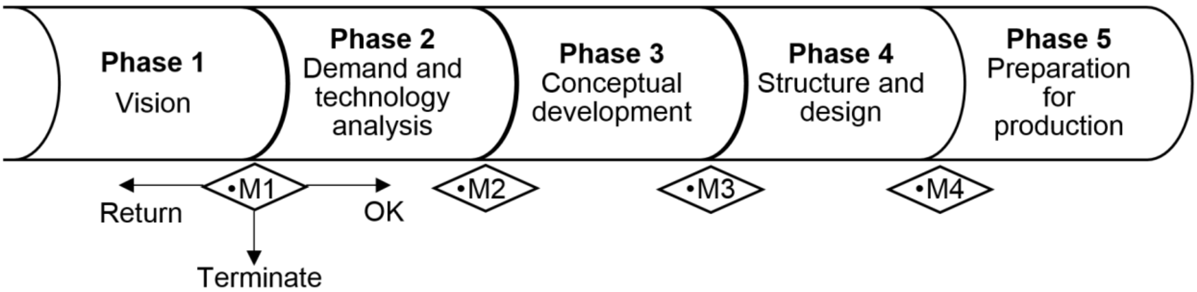

Figure 4: IPM model for product development (Grave 2013)

2.6.1 Phase 1 – Vision

The purpose of development is often to create good business in the organisation. Which means an optimal combination of market, product and production. Phase 1 is where essential parts like vision, mission, project plan and conditional framework are gathered in a project specification. Questions like "*What is the purpose?", "What do we want to achieve?*", "*How do we get there?*" and "*What is the domain we are working within?*", are relevant to answer in this phase.

2.6.2 Phase 2 – Demand and technology analysis

Phase 2 aims to analyse the market through reviewing current and potential usage and technology. *The user, user situation* and *usage method* are the three parts in a usage analysis where the demands and wishes are mapped. An in-depth understanding of the user and the user situation is a prerequisite for creating competitive advantage. The usage analysis forms the basis for the user demand specifications. Technology specifications together with the user demand specifications forms further the basis for the product requirement specifications. The product requirements are also partly a quantification of the user demands.

In a product development project, the developers are dependent upon having a framework to work within. This framework is given by specifications, like user demand specifications, product requirement specifications and technology specifications.

THE USER

There are many people in contact with a product during its life phase. All the way from production through sales, transport, installation, use, maintenance, service, dismounting, recycling and disposal, different people are affected by the product. Only a few of them are commonly understood as direct users, but all these stakeholders need to be considered in order for the product to be successful.

USER SITUATION

The purpose of mapping the user situation is to give the developer an insight to what situations the product will be used in. What is the most typical time and place for use? What kind of situation is this, and what are the circumstances? It is important to have an understanding of the normal use, but it is also necessary to have an insight in extreme situations.

USAGE METHOD

Usage method is closely related to user situation, but it is not exactly the same. Different users can use the same product in the same situation, however in different ways. A product will be used differently, and this is why usage method is important to understand.

USER DEMAND SPECIFICATIONS

The needs, demands and wishes are described in a *user demand specification*. This specification is independent of technology, which means that the specifications express what the stakeholders want, not how the demand should be fulfilled.

The demands can be organised based on the different stakeholders as shown in Table 6. If every stakeholder is interviewed or observed to obtain a list of user demands, it can become a lot to consider for the developer. To differentiate the demands, they can be further labelled as must, should and could. Another alternative is to rank the demands from 1 to 5 representing the relative importance of it.

	Must	Should	Could
Stakeholder A			
Demand 1	X		
Demand 2		X	
Stakeholder B			
Demand 3	X		
Demand 4			X

Table 6: User demand specifications

TECHNOLOGY SPECIFICATIONS

Limitations in technology occur very often due to availability and economy, and sometimes to what technology that is allowed. *Technology specifications* describe what technology should be used. Most product development projects base the development on already existing technology. The technology available can heavily facilitate or restrict the potential of the product.

PRODUCT REQUIREMENT SPECIFICATIONS

These specifications describe how the product should perform, not what it should do. *Product requirement specifications* are an accumulation of demands and requirements that proves to give the best base for the development. Development of an entirely new product should have few and wide specifications. Improvement of existing product on the other hand needs to have many and narrower specifications in order to fit already existing interfaces. Depending on type of product and project, the specifications can be sorted in different kinds of requirements. Table 7 shows some relevant types of requirements. The requirements must be unambiguous and measurable, and the value of the requirement can be either an absolute number or a range.

	Example values	Unit
Functional requirements …	> 2	
Ambient requirements …	0	
Operational requirements …	0	
Maintenance requirements …	100 -1000	
Reliability requirements …	0.95	
Safety requirements …	≤ 3	
Design requirements …	105 - 115	
Other requirements …	≥ 12	

Table 7: Product requirement specifications

2.6.3 Phase 3 – Conceptual development

The purpose of *concept development* is to find new solutions and to end up with a well-considered concept with a great potential. It is about generating and evaluating solutions, and normally a large solution space is examined by generating plentiful alternative solutions. Generating concepts is a quick and cheap process and it is usually at this point the good solutions arise. Important aspects of the concepts are described in detail, while other aspects are only roughly described or left out.

CONCEPT GENERATION

There are several ways of generating concepts, and some of them are described briefly here:

- *Define the problems.* After all the problems and issues are uncovered, a search for solutions will generate concepts.
- *Principle of orthogonal concepts.* The starting point of orthogonal concepts is to define some contrary directed and extreme themes for the concepts. The purpose is to loosen up the solution space and to avoid traditional solutions. Typical orthogonal concepts can be *the everlasting, the modular, the do-it-yourself, the automatic, the free,* and *the all-in-one*.
- *External search.* Someone might have come up with a solution for your problem already. Scientific literature, publications and patents can be useful for looking for ideas and solutions.
- *Internal search.* It is highly likely that others within the company, even though they are not part of the development team, have good ideas and solutions. Colleagues have an invaluable insight.
- *Analogue markets*. Two totally different products may have some shared demands or functions. An example is the use of the same material in Formula 1 tyres and in the sole of a shoe. This can work because the function, to have good grip between the object and the asphalt, is the same.

A *morphological box* is another method to generate and systematise solutions based on functions. Morphology means form or structure, and can be related to how a product is built up by functions. A product is often built up by several functions and each function needs own solutions. One function can be solved by different potential solutions. All these sub-solutions can be combined in different ways and create a set of complete solutions like shown in Figure 5. The theoretical number of possible combinations can be very high, but not all of these are feasible.

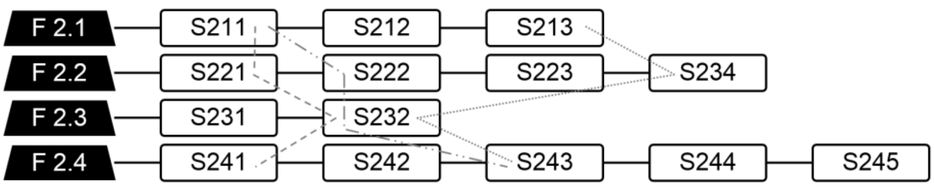

Figure 5: Morphological box with three complete solutions ensuring four sub-functions (F) (Grave 2013).

When a set of solutions is chosen to solve a set of functions, their logical structure, geometry and spacial appearance are still not chosen. They are just principles. By varying how the different sub-solutions and components are connect to each other and how they are placed related to each other, new conceptual solutions will arise. This is called *structural variations*.

CONCEPT EVALUATION

When as many concepts as possible are generated, it is easier to be sure that the best solution is actually on the table. With a huge amount of concepts it is important to have a method of finding the one with the greatest potential. An *evaluation matrix*, Table 8, can compare different concepts based on selected evaluation criteria. The criteria could come from product requirements specifications and can be numerous. Some criteria can have a higher importance, and to deal with that, a weighting can be introduced.

		Concept			
		A		B	
	Weight	Rating	Score	Rating	Score
Criteria 1	90 %	5	4.5	3	2.7
Criteria 2	10 %	2	0.2	4	0.4
Weighted score			4.7		3.1

Table 8: Evaluation Matrix with two concepts and two criteria

To decide how much each criteria should be weighted, a pairwise comparison can be carried out. *Pairwise comparison* is an easy way to find the most important criteria based on a comparison of two by two criteria. Reading from the second row (C1) and downwards, Table 9 shows that C1 is more important than C2 (marked with ‘2’), C2 is equally important as C3 (marked with ‘1’) and that C3 is less important than C1 (marked with ‘0’).

	C1	C2	C3	Sum	Distribution
C1	-	2	2	4	66.7 %
C2	0	-	1	1	16.7 %
C3	0	1	-	1	16.7 %

Table 9: Pairwise comparison of three criteria (Salustri 2005)

2.6.4 Phase 4 – Structure and design

A detailed design is made based on the solution selected in phase 3. Since only the concept is decided, the detailed end design can still have several outcomes. The base for further detailed development is to describe what functions the different components should have, and the next will be to create functional faces. A *functional face* is that part of a component that is actually solving a task.

FUNCTIONAL FACE VARIATION

When you know what kind of parameters that decides a components functional faces, variation in functional faces can be a space for finding ideas. Through a systematic variation in the input parameters, several groups of functional faces can be found for a given component. Varying parameters for the functional faces can be numbers, placement, geometry or dimensions.

Also in this phase, shape, structure and materials are applied to the components. 3D-models are made and the actual design is brought to an end.

2.6.5 Phase 5 – Preparation for production

The form, functions, material and technological principles are already given. This phase deals with all the preparations related to production. This can be tolerances and fit done in a CAD-program, as well as surface treatment. Also resources, tools, economy and type of production must be discussed to have a successful production. For instance, should it be a push or pull production? The product usually has a goal of reaching the market, and it is necessary to clarify all relevant deadlines. The product must reach the market in time with an appropriate price.

2.7 Test procedure for usability testing

To validate that a product or a system is working it needs to be tested, and each product requires individual test procedures. Without testing, it is difficult to know if the product works and also to know whether it is an improvement of a previous product.

When trying to measure usability and user experience, it is important to know something about the users and what they are trying to accomplish. Is the user imposed to use the product every day as part of their job, or necessitated to use it for medical reasons? Is the user likely to use the product only once? It is vital to understand what matters for the user. Does the user simply want to complete the task, or is efficiency a primary driver? Does the user at all care about the visual design of the product? All these questions boil down to measuring two main aspects of the user experience: the objective performance and the subjective satisfaction (Tullis and Albert 2013).

2.7.1 Performance

Performance is all about what the user actually does when interacting with the product. It includes measuring the degree to which a user can successfully complete a task or a set of tasks. Also aspects related to performing these tasks are important, and could be the time it takes to perform each task, the amount of effort, the number of errors committed, and the amount of time it takes before the user can perform the tasks without supervision. Performance measures are critical for many different types of products and systems, especially those where the user does not have a choice in how to use the product. If a user cannot successfully perform important tasks when using a product, the product is likely to fail (Tullis and Albert 2013). Furthermore, performance can be divided into effectiveness, which about doing the right task, and efficiency, which considers doing things in an optimal way (ISO 9241-11:1998).

A test procedure needs metrics to test against. It can be difficult to select appropriate indicators for a particular study, but Tullis and Albert (2013) have provided a table of *Ten Common Usability Study Scenarios and Their Most Appropriate Metrics*. For scenarios related to "*Maximising usability for a critical product"* and "*Comparing alternative designs"*, they suggest among others to use task success, task time, errors and efficiency. *Task success* is perhaps the most widely used performance metric, and measures how effectively a user is able to complete a set of tasks. It can either be measured as binary success or as levels of success. *Time-on-task* is a simple and common performance metric that measures the amount of time used to complete a task. The metric of *errors* represent the mistakes made during a task. Errors can be very useful in pointing out especially confusing or misleading parts. *Efficiency* can be assessed by examining the amount of effort a user spends to complete a task, such as the number of movements needed to fulfil the task (Tullis and Albert 2013). Efficiency can also be measured by tasks completed per unit time, momentary cost of performing the task or time spent on correcting errors (ISO 9241-11:1998).

Measures for *effectiveness* could be the percentage of goals achieved, percentage of users successfully completing tasks or average accuracy of completed tasks (ISO 9241-11:1998).

Several issues should be considered when choosing metrics. The technology that is available to collect and analyse the data, and the budget and time available, are important considerations. In addition, it is recommend to explore the test data and develop new metrics that add extra understanding or value for the specific project.

2.7.2 User satisfaction

Satisfaction is all about what the user says or thinks about the interaction with a product or system. The user might report that it is easy to use, that it is confusing, or that it exceeds expectations. The user might have opinions about the product being visually appealing or untrustworthy. Satisfaction is especially important for products where the user has a choice to choose an other product or supplier (Tullis and Albert 2013). Is important for the economy to address user satisfaction (Anderson et al. 1994), but is difficult to measure through performance. Satisfaction must therefore be measured in an own way.

One of the most commonly used questionnaires for measuring satisfaction through perceptions of usability is the *system usability scale* (SUS). The scale was released by John Brooke in 1986 and has since become an industry standard with references in over 600 publications. SUS is a quick, simple, reliable and technology independent tool to measure the satisfactory part of usability. It consists of 10 questions with 5 response options ranging from '*strongly agree'* (1) to '*strongly disagree'* (5) (Sauro 2011).

The 10 questions are the following:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

(Brooke 1996)

Calculating the total SUS-score is complex. For odd-numbered questions, 1 is subtracted from the user response. For even-numbered questions, the user response is subtracted from 5. Then all the converted responses are added for each user and multiplied by 2.5. This converts the range of possible values to 0 to 100 instead of from 0 to 40 (Sauro 2011).

Independently of technology and business areas, the average SUS score from 500 studies performed by Sauro (2011) was demonstrated to be 68. A SUS score above 68 would then be considered above average. He also compared the SUS score with the net promoter score and found that a score above 80.3 is needed to be among the top 10 % of scores. This is also the score where users are more likely to recommend the product to friends or colleagues.

The SUS has several benefits. It is a very easy scale to understand for participants. It is valid, which means it can effectively differentiate between usable and unusable systems. SUS also correlates highly with other questionnaire-based measurements of usability. And lastly, it is reliable. SUS has been proven to be more reliable and detect differences at smaller sample sizes than most other available questionnaires. Sample size and reliability are unrelated, so SUS can be used on very small sample sizes and still generate reliable results (Usability.gov 2013a).

2.7.3 Test procedure design

Based on performance and satisfactory metrics, a test procedure can look like this:

- A test person is introduced to the system and has the opportunity to read the installation steps a couple of times.
- The tester installs the system while being recorded.
- After the test, the tester answers the SUS questionnaire (Appendix 8.5). This will then measure perceptions of usability and the user insight can be understood. It will also be possible to compare the usability between two different systems.

After a test installation, the recordings needs to be reviewed and the different activity steps clocked. The task success is also registered with the assignments 1 = complete, 0.5 = completed with assist/correction and 0 = incomplete/error. An incomplete step is an error. If an error occurs, the task will be incomplete unless it is corrected.

With a registration table as the one composed below (Table 10), several metrics can be calculated.

	Task success						Task time					
	Current system			New system			Current system			New system		
	Test #1	Test #2		Test #3	Test #4		Test #1	Test #2	Average	Test #3	Test #4	Average
Activity step #1												
Activity step #2												
Activity step #n												

Results	#1	#2	avg.	#3	#4	avg.	#1	#2	avg.	#3	#4	avg.	change
Number of steps													
Steps completed													
Task success													
Number of errors													
Number of errors that was fixed													
Time used to correct errors													
Total time [seconds]													
Total time [minutes]													
Time, % of the best													

Table 10: Example of registration table for performance.

In this way, effectiveness is assessed by examining the task success, number of errors and the percentage of users that successfully complete all tasks. Efficiency will be assessed by examining the amount of effort a user spends to complete a task, like the number of steps needed to fulfil the task, by time to complete a task, and time spent on correcting errors. Additionally, when all the steps are clocked, it will be possible to see which activity steps that takes the most time and its percentage of the total task time.

2.8 Research design

A research needs a design or a structure before data collection and analysis can begin. A *research design* is not the same as a work plan. A work plan explains what should be done to complete a project, but the work plan will evolve from a project's research design. When constructing a building, it is important to know what kind of building that is needed before materials can be ordered and a milestone schedule can be made. This building analogy can relate to research design and work plan. A research design refers only to the structure, not the method, and can in principle use any type of data collection method. It is a logical matter rather than a logistical one (De Vaus 2001). Based on what is already know around the research question and what purpose and desired outcome that is related to the research, the research can be designed in different ways.

The sixth edition of the OECD's Frascati Manual (2002) defines *research* and experimental development as "*A creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications"*. In its most conceptual sense, research is nothing more than the search for understanding (Hirschheim 1992).

Once the research question has been formulated, it is critical to select an appropriate *research form*. There are several forms of research attempting to systematically describe, explain, understand, predict or control some observed phenomenon. These forms can be classified into four main forms based on the specific purpose:

- *Basic Research* - This research is descriptive in nature and is used to understand and explain a phenomenon. This type of research is often conducted to increase and advance a knowledge base.
- *Applied Research* - The purpose of this research is to provide information that can be used and applied in an effort to help people understand and control their environment. This type of research is more prescriptive and seeks to offer potential solutions to problems.
- *Evaluation Research* - The purpose of evaluation research is to examine the processes and outcomes associated with a particular solution to a problem. The research may be formative in the way that it attempts to improve the solution or it may be summative and attempt to evaluate the effectiveness of a solution.
- *Action Research* - This research is often conducted within a program, organization or community and the researchers are involved in gathering data and studying themselves.

(Center for Innovation in Research and Teaching 2012)

Basic research is of descriptive character while applied research is of prescriptive. *Descriptive research* is about describing how reality is, while *prescriptive research* is primarily concerned with the question how the reality *should be*. Descriptive research is making inventories while prescriptive research is normative (Van der Voordt and Lans 2002).

Research can furthermore have two main approaches - quantitative and qualitative methods. *Quantitative methods* are used to examine the relationship between variables with the primary goal to analyse and represent that relationship mathematically through statistical analysis. *Qualitative methods* are chosen when the goal of the research problem is to examine, understand and describe a phenomenon. Once the main approach to the research problem has been determined, there are several research designs for each type of approach that may be considered (Center for Innovation in Research and Teaching 2012).

The types of research designs usually related to quantitative methods are correlational, casual comparative, experimental and quasi-experimental designs (Center for Innovation in Research and Teaching 2012). Research design types related to qualitative methods are case study, narrative, grounded theory, phenomenology, ethnographic, historical and action research studies (Nieswiadomy 2008).

Two of the most relevant research designs are case study and action research.

CASE STUDY

A *case study* is an in depth study, rather than a statistical survey, of a particular situation. It will not answer a research question completely, but it will give some indications and allow further elaboration and create hypothesis creation on the subject (Shuttleworth 2008). A case study may be considered as quantitative or qualitative research depending on the purpose of the study and the design chosen by the researcher (Nieswiadomy 2008).

Some argue that because a case study is such a narrow field that its results cannot be extrapolated to fit an entire question. On the other hand, it is argued that a case study provides more realistic responses than a purely statistical survey (Shuttleworth 2008).

ACTION RESEARCH

Action research is research that strives for action in order to improve a current practice and to study the effects of the action that is taken (Streubert and Carpenter 2002, cited by Nieswiadomy 2008). No effort is made to generalise the findings of the study, as it is in quantitative research studies. In action research, the implementation of solutions is an actual part of the research process, and there is no delay in implementation of the solutions (Nieswiadomy 2008).

Action research aims to contribute both to the practical concerns of a problematic situation and to elaborate on the scientific knowledge. There is in other words a dual commitment in action research to study a system and concurrently to collaborate with members of the system to change it (Gilmore et al. 1986, cited by O'Brien 1998).

Action research has also a social dimension. The research takes place in real-world situations, and aims to solve real problems. The initiating researcher makes no attempt to remain objective, but openly acknowledges its bias. A situation where decision-makers in an organisation are aware of problems, but lack requisite methodological knowledge to deal with it, is not unusual. This is a typical situation where academics are invited into the organisation for action research (O'Brien 1998).

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3 Case Study: A Value Based Design Review of Existing Flood Protection System

AquaFence' flood protection system has been on the market for about a decade. Flood is increasing (World Meterological Organization 2014), and so is competition. Objective II and III in this thesis says that an improved design that has additional value should be developed, done in a holistic perspective. To successfully develop a redesign with added value, it is a necessity to understand the current system, and a case study of AquaFence' current flood protection system is now introduced. Moreover, objective I says that this thesis should contribute to the research and development collaboration between AquaFence and NTNU by providing an in-depth knowledge of the current system. This objective will be achieved in its entirety by executing this case study.

This chapter is considered a case study because it involves an in depth study of a particular object and will give some indications for further elaboration (Shuttleworth 2008). The case study takes the form of basic research with a descriptive and qualitative approach since the study seeks to examine, understand and describe how the system is per se (Van der Voordt and Lans 2002, Center for Innovation in Research and Teaching 2012).

This chapter and case study comprises several stages and is framed based on phase I and II of the value study job plan.

Phase I, which is the information phase establishing the context and the current conditions (SAVE International 2007), starts by describing the history and background of AquaFence, and roughly how the product works. A section decomposing the system and defining different system terms is included in order to have a clear and unambiguous understanding of what is being discussed.

The next sections covers different stakeholders' thoughts and concerns, a description of the situations and circumstances under which the system is used, and problems and issues related to the current system. An assessment of stakeholders, user situation and problems are part of the IPM model phase 2 - demand and technology analysis (Grave 2013).

The value analysis job plan phase I ends with a test of the current system, measuring installation time, installation errors and the usability using the system usability score. Phase I is followed by phase II consisting of the perhaps most important activity in the value analysis, the functional analysis (Crow 2002).

All the sections described hitherto leads to a set of demands and requirements in Section 3.9, and the entire chapter ends with a summary including the main findings from the case study.

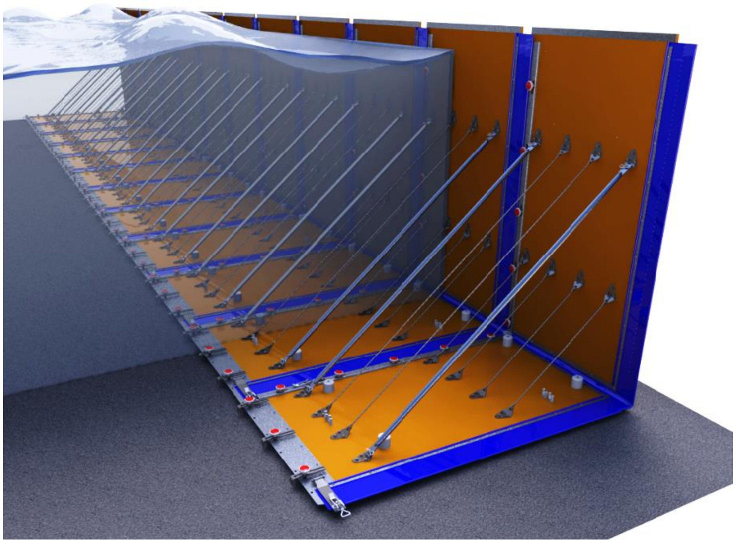
A visualisation of the chapter and case study scope is provided in Table 11.

Value Analysis	Job plan phases	Section		IPM phase	
Value Workshop	Phase I – Information	3.1 - History of AquaFence			Case study
		3.2 - Functionality			
		3.3 - A systematic breakdown of the flood protection system			
		3.4 - Stakeholders		Phase 2 – Demand and technology analysis	
		3.5 - User situation			
		3.6 - Problems and issues			
		3.7 - Installation and installation time			
	Phase II – Functional analysis	3.8 - Functional analysis			
		3.9 - Synthesis of demands and requirements	DfX Applied	Phase 2 – Demand and technology analysis	
		3.10 - Summary			

Table 11: Visualisation of Chapter 3 and case study scope

3.1 History of AquaFence

The history of AquaFence starts back in 1997 when the Norwegian University of Life Science started a collaboration with an inventor with the aim to overcome some of the problems associated with sandbags. Sandbags are very time and resource consuming to install and remove. Since the flood water can be contaminated, sandbags may be considered as hazardous waste and must be treated accordingly. The intention was also to develop flood protection equipment that could function as a supplement to conventional earth embankments (Bjerkholt and Lindholm 2007).



Picture 1: A standard V2100 aquafence deployed

The company AquaFence was founded in 1999, but it was not before the second half of the 2000 decade that they reached the international market (Strøm-Gundersen 2007).

Today AquaFence has its corporate headquarter outside Oslo in Norway, while the production is done by AquaFence SIA Latvia in western Latvia. The product is used all around the world, and especially in USA, Thailand and Europe (AquaFence 2014c). The yearly production volume is 5 - 6 kilometres of flood barriers, resulting in a total sale of NOK 30 - 40 million (Dahl 2014).

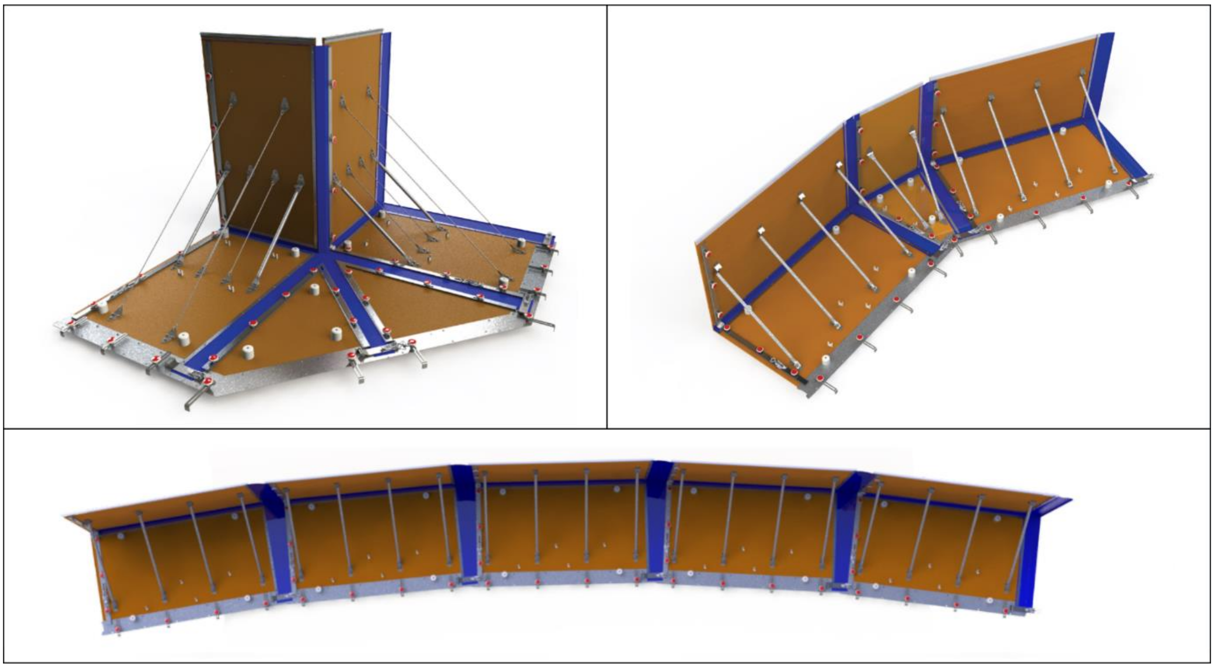
3.2 Functionality

AquaFence' flood protection system has a preferable use in densely populated urban areas where access, both physical and visual, to a rivers or lakes should be preserved. It can also be used in places where it is not possible to build high earth embankments or not possible to build such structures at all (Bjerkholt and Lindholm 2007).

The flood wall is a modular system that can be built in any desired length. It is put together by individual modules, or panels, made of marine grade laminate, stainless steel, aluminium and reinforced PVC canvas. The standard heights are 1.2 metres (V1200), 1.8 metres (V1800) and 2.1 metres (V2100) and weights respectively 85, 85 and 110 kg per panel. The V2100 panel can be extended to 2.4 meters by adding a top module.

The flood protection system is designed for rapid deployment around buildings within hours before a pending flood event. When the water rises, the weight of the water stabilizes the fence. Since the water applies weight on the horizontal part, the water strengthens rather than weakens the structure. Aluminium rods hold the panel in an upright position and takes the compression and tensile forces. Wires take only the tensile forces. Underneath the panel there is a foam gasket that seals the fence to the ground.

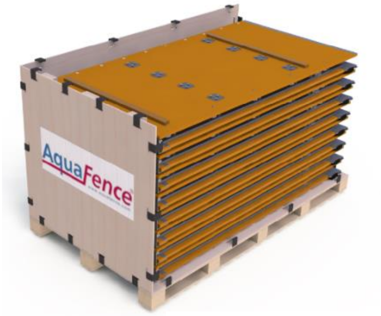
There are some situations where the product should not be used. Sandy, silty and unstable ground should be avoided due to the risk of floodwater eroding the ground under the panels. Also uneven or sloping surfaces greater than 5 degree slope change over the length of 2 panels, should be avoided if not a concrete foundation is installed in the ground first (Bjork 2013).



Picture 2: V1800 outside 90° corner, V1200 inside 45° corner and V1200 flexible curve

Due to the blue PVC canvas, the design is quite flexible, and an articulation between adjacent panels of 2.5 - 5 degrees can be obtained. For more sharp turns, special corner panels can be inserted to obtain inside or outside corners of 30°, 45°, 60° or 90°.

The length of the V1200, V1800 and V2100 are respectively 2.1, 1.2 and 1.2 meters. This means that they all can fit into same 2.3 x 1.3 x 1.3 meters crate (Picture 3). The panels are piled 8 - 9 on high in each crate, and 18 of these crates are stacked in 40” high cube container before they are shipped worldwide. Furthermore, depending on the model selected, a given number of crates is necessary to install a desired length of flood protection. A calculation for this is shown in Table 12.



Picture 3: A crate with 8 panels

	Model	Panels	Crates	Total weight [kg]
250 meters	V1200	126	14	12 278
	V1800	216	24	21 048
	V2100/2400	216	27	24 624
500 meters	V1200	243	27	23 679
	V1800	423	47	41 219
	V2100/2400	424	53	48 336
1000 meters	V1200	477	53	46 481
	V1800	837	93	81 561
	V2100/2400	840	105	95 760

Table 12: Number of panels and crates for given flood barrier lengths

For installation, the first thing to be done is to place one crate of panels for every 19 meter for model V1200 and for every 11.5 meter for model V1800 and V2100. Secondly all the panels needs to be placed side by side in a long line. When this is done, the panels can be raised, secured and connected (Picture 4) to each other. The process of connecting them will be described in more detail in Section 3.7.

Picture 4: Canvas from the first panel (to the left) secured by the canvas clamp on the second panel

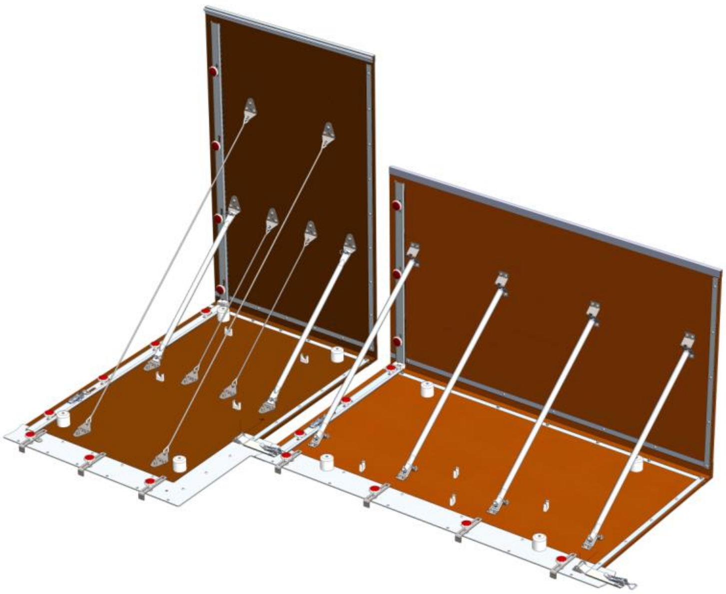
After deployment the panels are cleaned, inspected, packed and stored for later use.

There are several additional elements available that can be included in the system. A protective shield to withstand impact from floating debris (Picture 5), side closures for fixing the panels to walls (Picture 6), wind load support and anchoring are some.

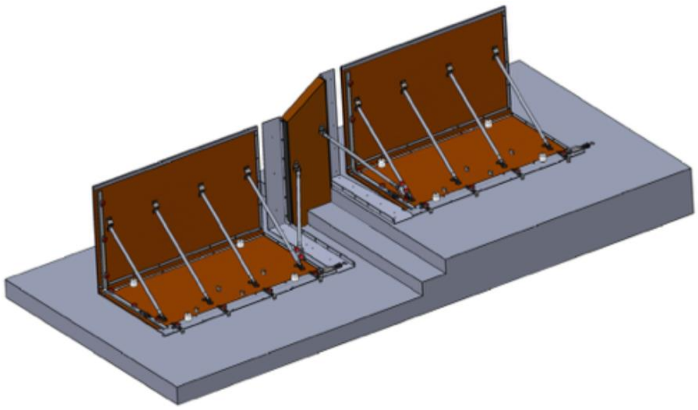
Variations of the panel are made to cope with stairs (Picture 8), obstacles (Picture 9) or the need for different panel heights (Picture 7). If this is not enough, the system can be custom made. The system can be combined with existing levees.

Picture 5: Protective shield

Picture 6: Side closures to connect flood barriers to a wall or fixed surface

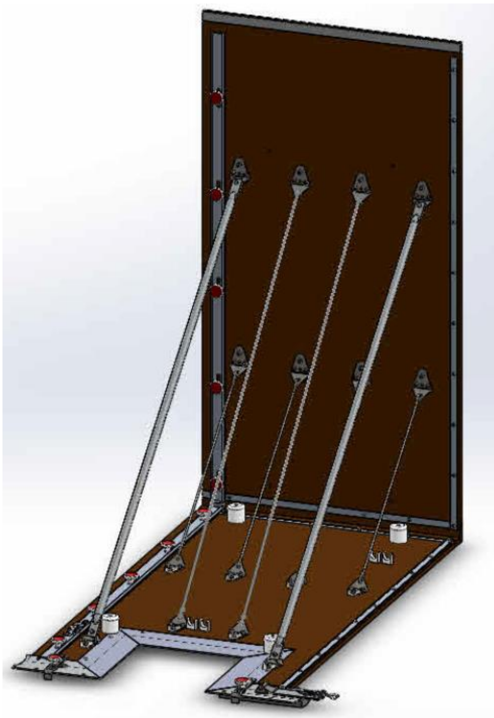


Picture 7: Solution to combine flood panels of different heights



Picture 8 (above): Solution to cover steps

Picture 9 (right): *V2100* panel *with a "cut out" in the front, in order to overcome a pillar*



3.3 A systematic breakdown of the flood protection system

Even though this flood protection system does not include any electronics or hydraulics, it is a quite complex system. As mentioned in the introduction, this thesis will not consider the entire flood protection system, but a part of it. This section will use systems theory (Section 2.5) to describe and define different system terms related to the flood protection system that will be necessary in order to have a clear and unambiguous understanding of what is being discussed.

Regarding a flood protection system the *environment* influences the system from the outside. Water, ground, weather and people are examples of that. The flood protection system, which is the *main overall system*, can be broken down into *sub-systems* and *system elements* (Figure 6). Each sub-system and system element additionally has its own sub-systems and system elements which in turn also can be decomposed. One of the sub-systems, which is the *system of interest* in this thesis, is the system of connecting to panels to each other. This is marked as sub-system #1 in orange in the figure. Other examples of sub-systems is that of fastening the panel to the ground. The panel itself is a system element of the overall flood protection system (system element #1). The system for holding the panel in an upright position, is a sub-system of the system element '*the panel*', and is also considered an *enabling system* for the system of interest. Between all the elements, the sub-systems and the environment, are *interactions*. For simplification, not all the interactions, sub-systems or system elements are drawn in Figure 6.

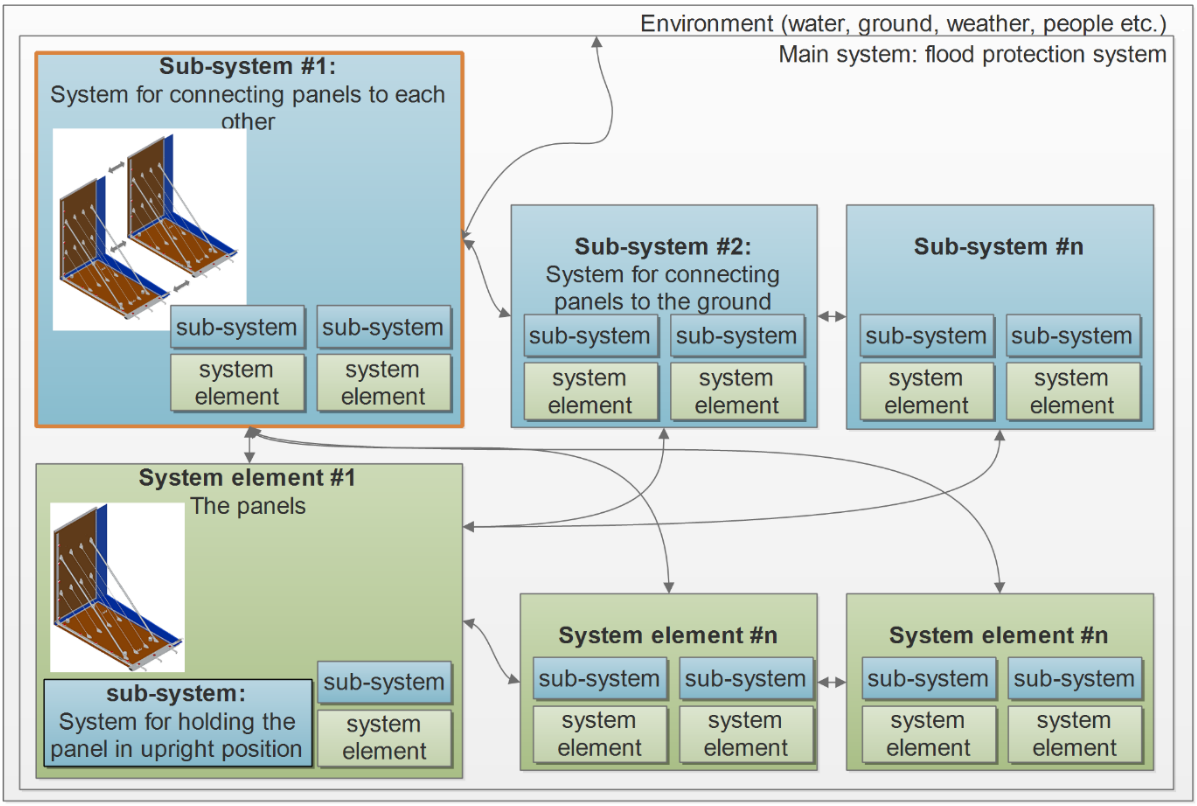


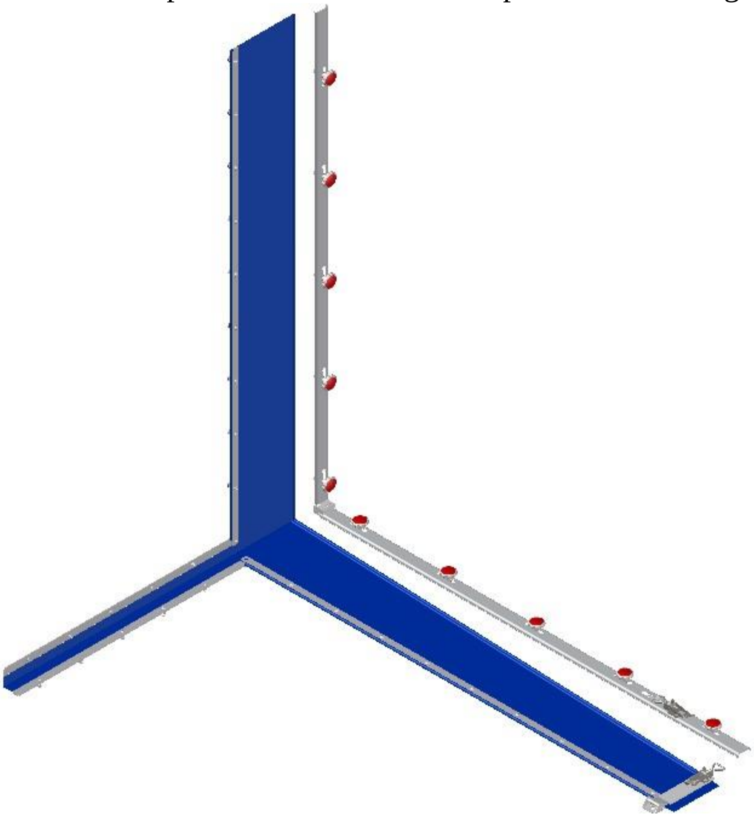
Figure 6: Flood protection system decomposition and interactions

The system of interest is the system of connecting two panels to each other, and that is what this thesis deals with.

The system of interest consists of system elements like canvas clamps, fastening wheels, canvas lock sheet, eccentric lock, screws, bolts and the canvas itself. This is highlighted in Picture 10. The only exception is the system element the longitudinal eccentric lock in the bottom right of the picture. That part is not considered in this study because the potential of improvements is very low (Dalsgaard 2014).

Picture 10: System of interest marked with green

Another way to visualise the system of interest is shown in Picture 11. The blue PVC canvas is from the left panel and the canvas clamps are from the right panel.

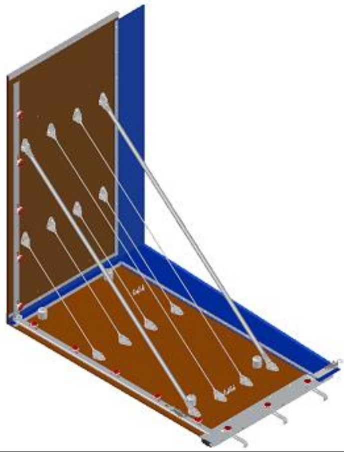


Picture 11: System of interest isolated

The elements indicated in Picture 10 and Picture 11 are of course interacting with other elements which need to be considered. These interacting elements will be consider as a limitary framework.

For consistency, comparability and simplicity, the focus and analysis will be on the V2100 standard panel. When a suitable solution for that panel is found, applicability for other models will be described.

For the rest of the thesis the term *the system* will be used for the system of interest, the system of connecting the panels to each other. Sometimes *the connection system* will be used. When talking about the entire flood protection system, the term *parent system* will be used. To understand and navigate in the jumble of system terms, Table 13 describes a list of terms and their definitions.

A panel	One single isolated panel that stands alone and is not interacting with other panels.	
Flood wall, aquafence, water/flood barrier	Several panels place side by side and connected will be referred to as a flood wall, an aquafence or a water barrier.	
Parent system, total system, (Today's) Flood protection system, the product	One or more flood walls that are arranged in a way that they intend to lead water away from property or areas. A flood wall is not considered a flood protection system before it is placed into a context.	

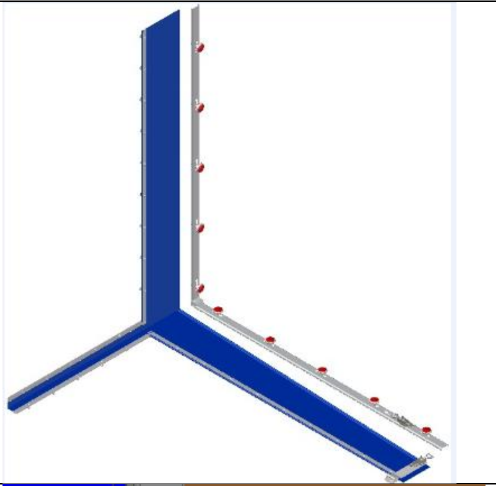
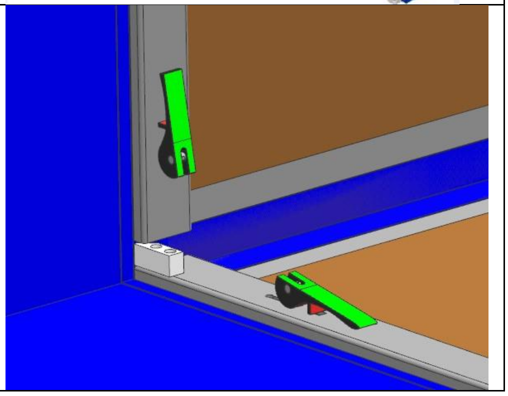
The system, system-of-interest, panel connection system, today's system, current system	The system of connecting two panels to each other that exists today. The system that is analysed in this thesis.	
The **new** system	The **new** system of connecting the panels to each other. The system that will be developed.	

Table 13: System terms and their applied definitions

The panels will be exposed to loads, forces, flex and movement in different directions. Figure 7, Figure 8 and Figure 9 show how each direction should be understood.

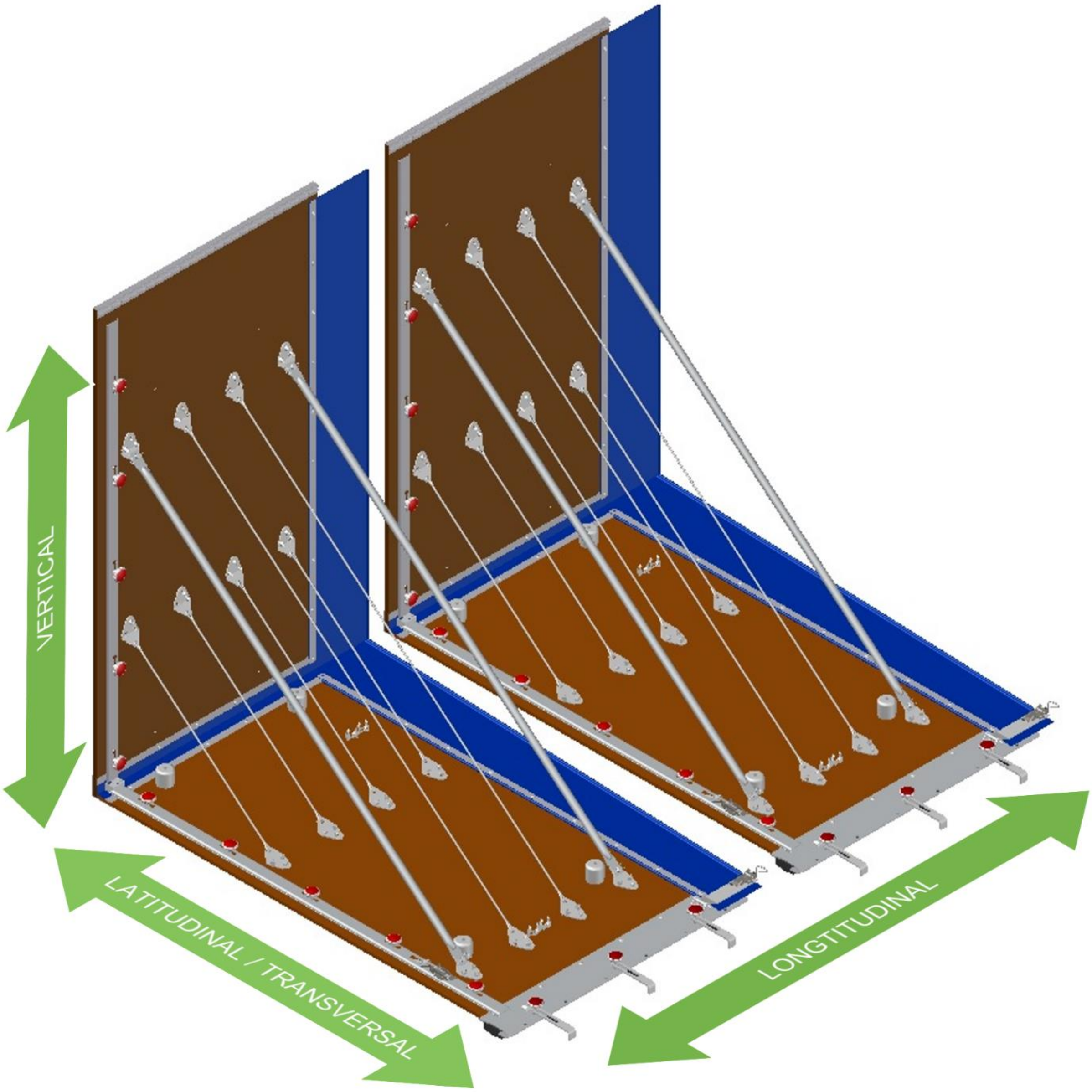


Figure 7: Vertical, latitudinal and longitudinal direction

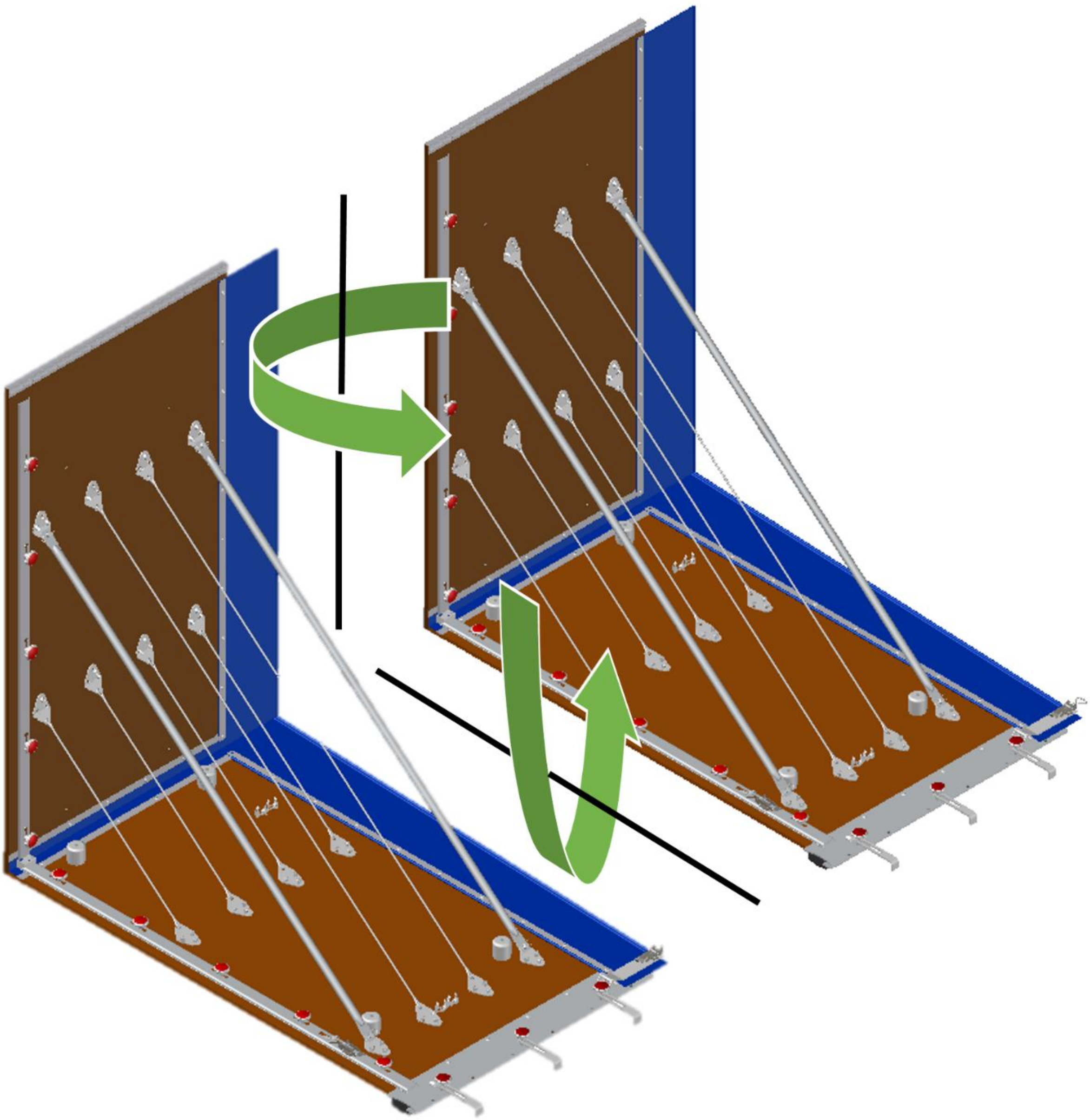


Figure 8: Horizontal and vertical rotation

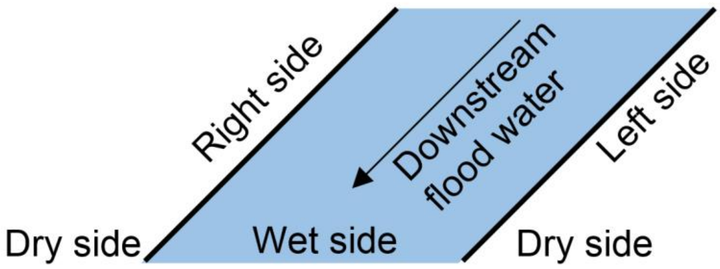


Figure 9: Aerial view of a flooding river and flood barriers

3.4 Stakeholders

In order to increase the value of the flood protection system, it is necessary to identify what kind of people have an interest in or are affected by it. An understanding of who they are, how they benefit, interact or are hindered by the flood protection system is useful. It is the stakeholders that gain the value.

The stakeholders identified are described in relation to the parent system, but they are also stakeholders of the system of interest because that is a sub-system of the parent system.

AQUAFENCE AS

A small group of people managing the company, doing development and supporting other parts of AquaFence. The product is their source of income. For AquaFence it is important that the flood barriers are safe and efficient to produce, that the customer value is high, and consequently that the margin is as high as possible. They are also concerned about quality, reputation and future markets. They are not necessarily in direct contact with the finished product.

SALES TEAMS

People located around the world, mainly in USA, Germany and Thailand, selling flood protection systems and working for AquaFence' interests. They are interested in having a quality product that solves problems for the users. It is also important that the product is appealing and have some competitive advantage so that it would be easier to sell. They get feedback from the customers very often. For the sales team it is also important that they have enough deliveries of flood barriers.

MANUFACTURING

The manufacturing facility is today located near the west coast of Latvia and is dedicated to AquaFence. For them it is important that it is easy to handle and assemble all the parts in the panels, and that the operations needed are safe to perform.

TRANSPORT

The transportation from factory to the customer is outsourced, so their interest in the product is limited as long as they get paid sufficiently. They appreciate that the goods are not dangerous or require extreme precaution.

OWNER/CUSTOMER

The ones that buy and own the flood panels from AquaFence. This is typically landlords, property owners, factory owners, municipalities or government. They are responsible or have stake for what is protected. They are interested in low costs and high value, performance and usefulness for the product. Furthermore they want the flood protection system to be quick to install, reliable, available, require little maintenance, solve the problems, safe, easy and efficient to store, and possible to dispose.

INSTALLERS

The installers are those putting up and installing the panels. They might be volunteers or employees, professional within emergency preparedness or not. They have various training, but they are all interested in having a system that is easy and efficient to install and adjust. Safety is also important.

THE PUBLIC

The people living within or in the vicinity of the protected area. They are very concerned about the reliability of the flood protection system. A feeling of safety is important. It is also important that they are not hindered from their normal activities for more time than necessary, and that the view or the visual townscape is not contaminated.

It is observed that several stakeholders have an interest in the flood barrier and that their focus is varying. Nevertheless, several stakeholders have the same concerns.

3.5 User situation

This section describes the situation and circumstances under which the flood protection system is used.

During the last four decades flood has become a bigger and bigger threat, and the number of reported flood related disasters has increased on a global level from a few hundreds in 1971 - 1980, to nearly 2000 in 2001 - 2010. 44 % of all reported natural disasters in the period 1970 - 2012 were due to flood. When it comes to cost, flood disasters cost approximately USD 200 billion worldwide in the period 2001 - 2010 (World Meterological Organization 2014).

Flooding is a phenomenon occurring when the water exceeds the capacity of the water system and water overflows onto land that is normally dry (National Severe Storms Laboratory 2012). There are several factors that cause a flood to arise, but increased precipitation and severe storms are the main categories for natural floods. Increased precipitation may cause regional floods, flash flood, ice-jam floods or landslide. Severe storms may lead to coastal flooding from seasonal peak tides, tropical cyclones, hurricanes, tornados, earthquakes, tsunamis or sea level rise (Watson and Adams 2010). AquaFence' flood protection system is intended for most of these cases.

Picture 12: A flood barrier in use protecting an entrance to a warehouse

The flood protection system is usually put in place ahead of a flood event, but the flood walls have also been installed after the water has started to rise. Installing them in deep water or during a heavy rainstorm is of course more demanding, but still possible.

Before the panels can be installed, they need to be transported from the storage and to the site. This can sometimes be a challenge if the panels are stored in a distant location, and the roads leading into the flood area are blocked for safety reasons or obstructed. If the flood panels are installed too early, they may hinder normal activity or traffic, and it is not given that the forecast is available well in advance. There will always be a consideration when to install the panels.

Picture 13: A truck loaded with crates filled with flood panels.

A flood barrier is often installed during a crisis situation which can be both chaotic and stressful. When the panels are installed, they will be affected by wind, water, sediments and floating debris. Such floating debris can damage the panels. If damage occurs to the PVC canvas while in service, a wooden board with a thick soft-cell rubber material can be installed from the water side of the system (Picture 15). The water will in this case apply force against the patch in the direction of the element, holding it in place and reducing the leakage. The panel can further be supported with wood screws from wet side of the wooden patch (AquaFence 2014b).

Picture 14: Damaged and repaired PVC canvas.

After a flood has receded, the panels need to be cleaned and inspected before they are stored in folded position until the next use. The recommendation is to store them in a dry location with no exposure to the sun and protected from rodents, but this is not necessarily always followed.

Other potential uses for the flood protection system is for spillage protection, when liquid substances need to be controlled.

3.6 Problems and issues

Today's solution has several problems and issues, and these have been identified through dialogue with different stakeholders or test persons. The issues are both direct problems, potential improvement areas and non-optimised solutions. Most of them are related to installation and operation.

3.6.1 Installation

During installation, both the fastening wheels and the canvas clamp have issues.

To tighten all ten fastening wheels is time consuming. When installing by hand it is often difficult to know if you have turned enough. You either use time to check if it is tight/loose enough or you turn more than needed. While turning, your knuckles very easily scratch against the aluminium profile of the canvas clamp. Installing the system with an impact wrench with a special socket adaptor is faster, but to rely on additional tools is not an optimal solution. When tightening the wheels there is also a problem that too much force can be applied from the impact wrench. This can damage the parts and affect further use. Most of the wheels are easy accessible, but on the V2100 panels it can be difficult to reach the uppermost fastening wheel. The final problem with the fastening wheels is the fact that the wires tend to snag in and around the wheels.

The problem with the canvas clamps is mainly that they need to be adjusted in a specific order, and the adjustment itself is not done easily. People tend to kick or hit the canvas clamp to reposition it. This can lead to deformation of the canvas clamp. In addition, the horizontal canvas clamp is sometimes in conflict with the longitudinal eccentric lock.

The problem with the canvas is that it often jumps out from the vertical canvas clamp when trying to fasten the fastening wheels. This means that you need to hold the canvas while you are fastening the wheels.

The installation is not intuitive, and sometimes people even forget to fasten the panels to each other.

3.6.2 Operation

During operation, both the canvas lock sheet and the vertical canvas clamp have issues.

The problem with the canvas lock sheet is that it does not seal 100 % in the corner. The sealing surface on the left side is 5mm thin and breaks very easily. The sealing surface on the right side has no function because it is the left side that pushes the PVC canvas into the panel. The right side actually hinders the left part from sealing properly.

When it comes to the vertical canvas clamp the issue is not major, but the matter is that there is a distance between the uppermost fastening wheel and the uppermost part of the vertical canvas clamp. This means that the end part of the canvas clamp is not pushed properly into the panel.

3.6.3 Removal phase

The issues in the removal phase are more or less the same as in the installation phase. The fastening wheels are time consuming, additional tools are needed and the uppermost fastening wheel can be difficult to reach.

3.6.4 Storage and transportation

The panels are quite heavy and this makes them more difficult to move and transport, so all saved weight is positive. The thickness of a panel when it is folded is strictly the height of the clamping system. If the thickness of a panel can be reduced, then more panels can fit into one crate.

3.7 Installation and installation time

AquaFence states that a team of 10 people can install about 100 meters (328 feet) of aquafence per hour (AquaFence 2014a). Since this project is not about the entire aquafence, an own time study related to the system of interest will be carried out.

To test how easy the system is to install and to examine the installation times, the test procedure presented in Section 2.7 will be used. In this way task time, task success, errors and satisfaction will be measured. The test consists of both a recorded time study and a SUS questionnaire.

Elements that are not presented in the test procedure earlier, but are special for this particular test are the following:

- Three tests have been carried out.
- Test #1 and #2 are done without the use of an impact wrench. Such equipment will usually be available during an installation, but since the system is intended for use in crisis, it is important to test for situations when the tools are not available. In a stressful situation, the impact wrench or the socket adaptor can be broken or missing, or simply that there are not enough tools for all the installers.
- Because of the previous bullet point, for activity steps where an impact wrench has been used, the average times are calculated only from test #1 and #2.
- The test was done with V1200 panels, but the results are extrapolated to represent V2100 panels.
- Average test times are an average of actually completed activity steps.

The installation procedure with all its activity steps are described in Table 14.

	Current system	Task success			Task time [sec]			
		#1	#2	#3	#1	#2	#3	avg.
1	Loosen the fastening wheels/cam levers on the horizontal and vertical canvas clamps.	1	1	1	103	72	43	87.5
2	Slide the PVC canvas under the horizontal and vertical clamps.	0.5	0.5	0.5	45	38	59	47.3
3	Pull up the vertical canvas clamp	0	1	1	2	3	1	2.0
4	Slide the horizontal canvas clamp against the vertical panel.	0	0.5	1	2	2	2	2.0
5	Hand tighten the fastening wheels on the horizontal clamp.	1	1	1	45	68	17	56.7
7	Fasten the latitudinal eccentric lock on the horizontal clamp.	1	1	1	10	7	4	7.0
8	Re-tighten the fastening wheels on the horizontal clamp.	1	1	1	42	17	13	29.2
9	Push the vertical clamp down firmly against the horizontal clamp.	1	1	1	1	2	3	2.0
10	Tighten the fastening wheels/cam levers on the vertical canvas clamp	1	1	0.5	70	67	50	68.3
11	Check that the eccentric lock on the horizontal clamp is secured.	1	1	1	1	1	1	1.0
12	Check that all the fastening wheels are tight	1	1	1	7	5	4	5.3
13	Loosen the fastening wheels/cam levers on the horizontal and vertical canvas clamp.	1	1	1	117	103	40	110.0
14	Slide the PVC canvas out from the horizontal and vertical clamps.	1	1	1	10	5	8	7.8
15	Pull back the horizontal canvas clamp	1	1	1	1	1	1	1.0
16	Lift the vertical canvas clamp	1	1	1	1	1	1	1.0
17	Fasten the fastening wheels/cam levers on the horizontal and vertical canvas clamp.	1	1	1	80	85	40	82.5

	#1	#2	#3	#1	#2	#3	Avg.
Number of steps	16	16	16				
Steps completed	14	16	16				15.3
Task success	88 %	100 %	100 %				96 %
Number of errors	3	2	2				2.3
Number of errors that was fixed	1	2	2				1.7
Time used to correct errors				3.0	3	24	10.0
Total time [seconds]				536	477	287	507
Total time [minutes]				8.9	8.0	4.8	8.4

Table 14: Task success and installation times for current system.

The results from Table 14 will be discussed in more depth in Chapter 5, but the table shows clearly that it takes around 8.4 minutes to install the system by hand and 4.8 minutes with the help of tools. It also shows that activity step 13 "*Loosen the fastening wheels/cam levers on the* *horizontal and vertical canvas clamp*" takes the most time and counts for 22 % of total time used. Regarding the errors, sliding the canvas underneath the canvas clamp is a source of error. See Appendix 8.5 for full calculations.

The scores from the SUS questionnaire after the installation is provided in Table 15. Question 1 was left out and scored neutrally (with 3 points) since the question is of very little relevance for the system tested.

		Question #										
		1	2	3	4	5	6	7	8	9	10	SUS Score
Test #	1	3	4	2	2	2	3	2	5	1	5	27.5
	2	3	4	3	2	2	3	3	5	1	4	35.0
	3	3	4	3	1	2	3	3	5	2	3	42.5

Table 15: Results from the System Usability Scale

The table shows that the system has a very low SUS score and also that the score is a bit higher when installation tools are used.

3.8 Functional analysis

This section describes today's system, all its components and which parts that solve which functions, through a functional analysis. This is done to provide a comprehensive understanding of the product, the product's functions, sub functions and preconditions (SAVE International 2007), and to identify excessive or redundant functions that lead to higher cost (Crow 2002).

The function tree in Figure 10 shows the hierarchy of the system decomposed into sub-systems, parts and functions and Table 16 describes all these different parts and what their functions are.

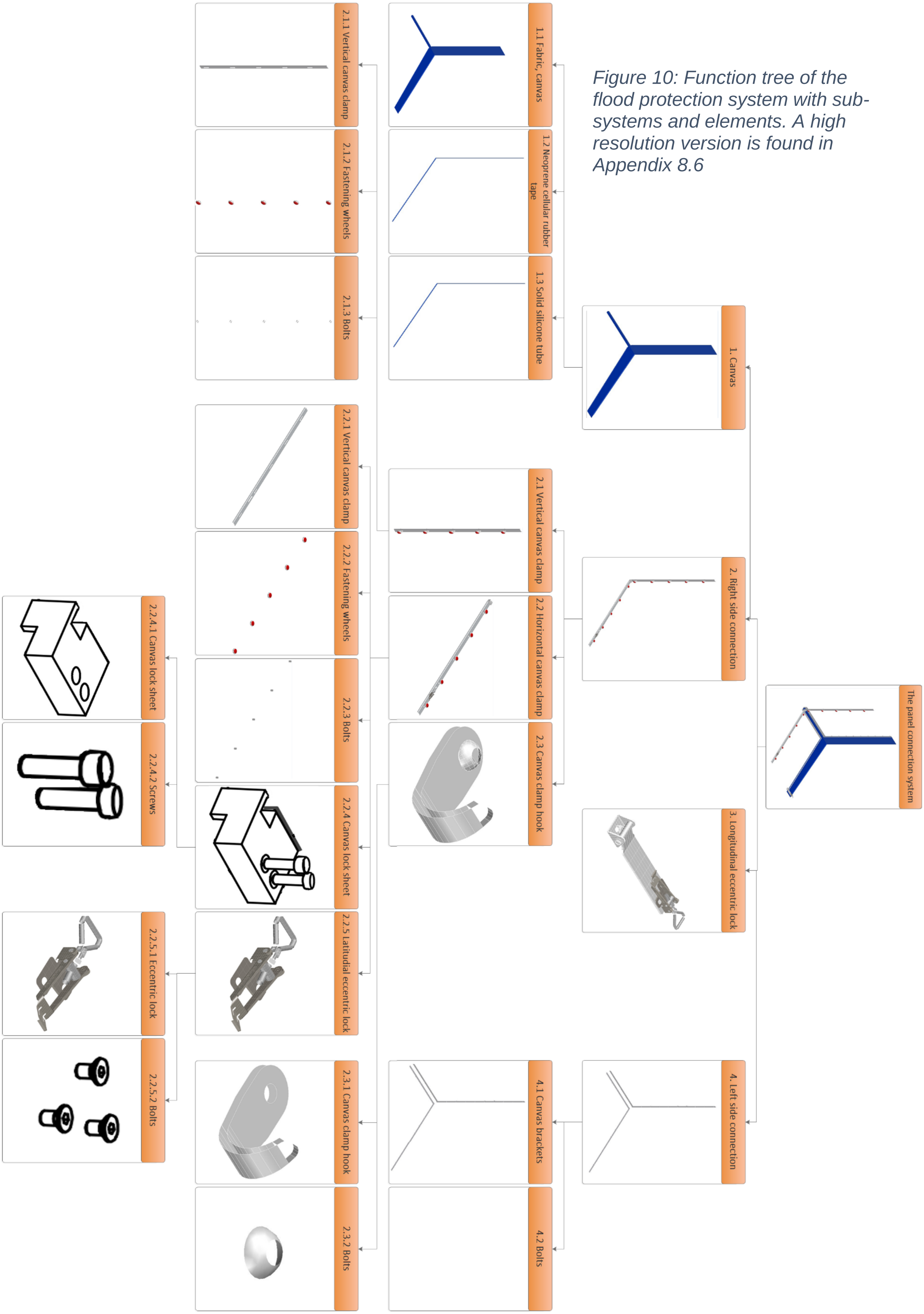
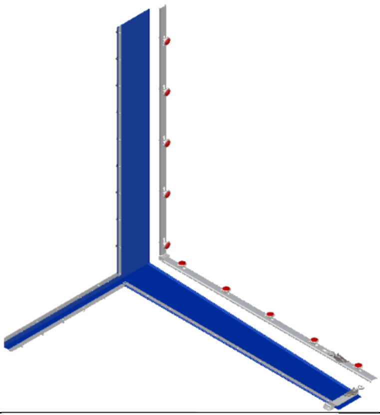
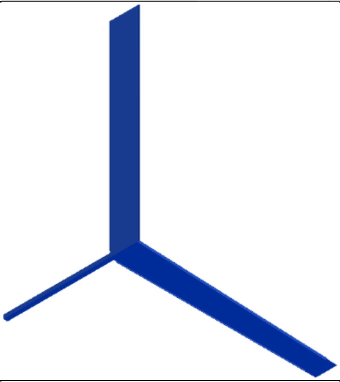
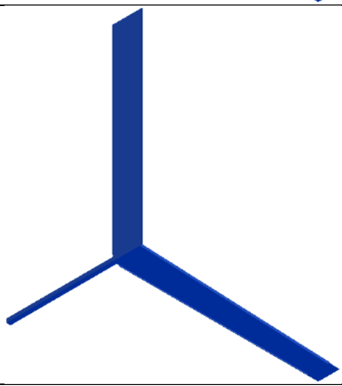
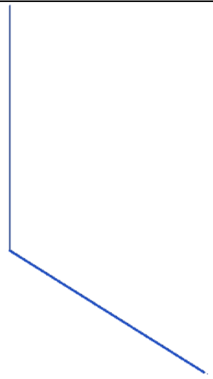
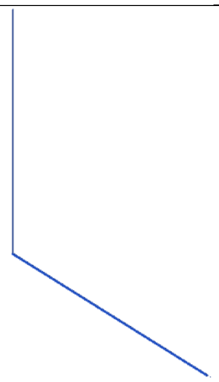
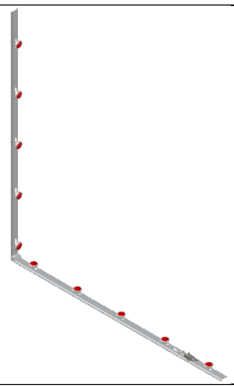
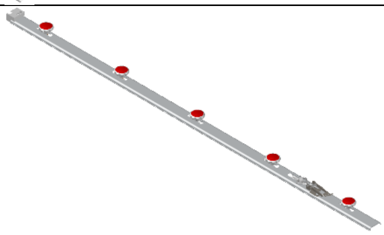
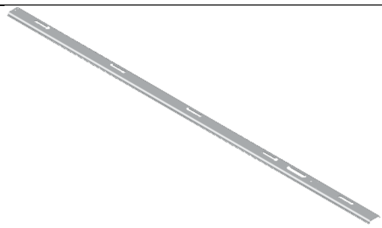


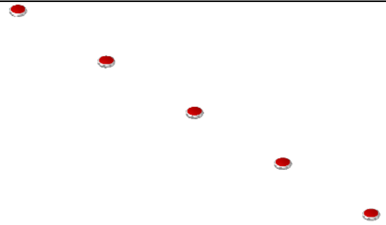
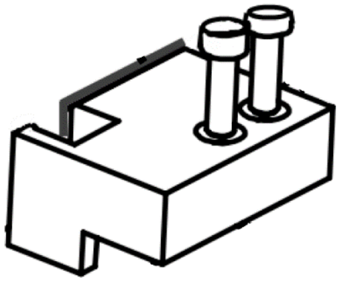
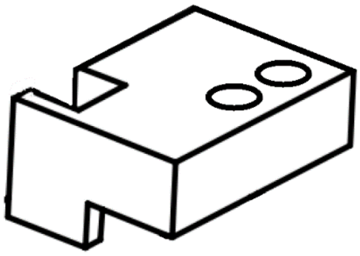
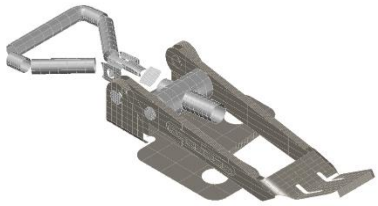
Figure 10: Function tree of the flood protection system with sub-systems and elements. A high resolution version is found in Appendix 8.6

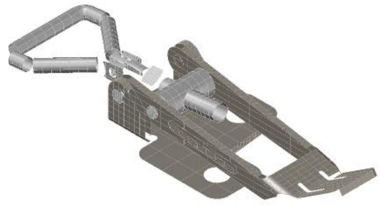
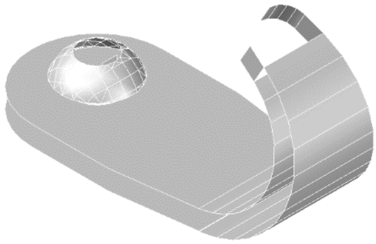
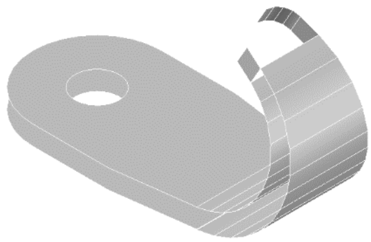
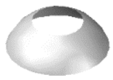
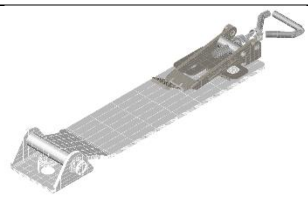
Main function in Table 16 describes the main purpose of the part. *Secondary function* describes what function it has in addition to the main function. *Relative importance* is how important a particular part is for the fulfilment of the function of the parent component. If a particular component has very little importance for the parent component, it should be considered eliminated. The *total importance* is how important a component is for the panel connection system. The numeric value of total importance is a product of all the relative importance percentages down the branch. The percentages are rough estimates that I have done.

0	THE PANEL CONNECTION SYSTEM **Main function:** Function is to connect panels together physically **Secondary function:** Keep the water on wet side of the fence. **Relative importance**: 98 %. If this component were absent, one would need to place the panels really close to each other. This would make the aquafence leak. The performance would also be decreased due to instability and less flexibility, both in the angular and in the longitudinal direction. **Total importance:** 98 %	
1	CANVAS **Main function:** Connect panels to each other physically. **Secondary function:** Keep the water on the wet side of the fence. **Relative importance:** 100 %. The canvas is the bridge between two panels that are connected. It is also the part that actually stops the water from flowing between the panels. **Total importance:** 98 % **Weight:** 1302 g	
1.1	FABRIC, CANVAS V2100 (PART #10098) **Main function**: Keep the connection between two panels waterproof **Secondary function:** Enable angular and longitudinal flex between two panels. **Relative importance**: 100 %. The canvas fabric constitutes more or less the entire canvas above. **Total importance:** 98 % **Material**: Polymer DIN ISO 2076, EN ISO 2060	

1.2	NEOPRENE CELLULAR RUBBER TAPE (4.3M) (PART #100048) **Main function:** Seal between the canvas clamp and the canvas. **Relative importance:** 60 % **Total importance:** 59 % **Material:** Neoprene cellular rubber	
1.3	SOLID SILICONE TUBE (INTEGRATED IN PART #10098) **Main function:** Stop the canvas from sliding away from the canvas clamp. **Relative importance:** 75 % **Total importance:** 74 % **Material:** Silicone	
2.	RIGHT SIDE CONNECTION **Main function:** Fasten the canvas to the second panel. **Secondary function:** Seal the Canvas to the second panel **Relative importance:** 100 % **Total importance:** 98 %	
2.1	VERTICAL CANVAS CLAMP **Main function:** Fasten the vertical canvas to the second panel. **Secondary function:** Seal the vertical canvas to the second panel **Relative importance:** 99 %. Without this part, a lot water will be flowing through the fence. **Total importance:** 97 %	

2.1.1	V2100 VERTICAL CANVAS CLAMP (PART #10120) **Main function:** Hold the canvas and the solid silicone tube so that it is not sliding **Relative importance:** 100 %. The vertical canvas clamp (2.1) would be useless without this part **Total importance:** 97 % **Material:** Aluminium 6063-T3 **Weight:** 1528 g	
2.1.2	FASTENING WHEEL M8 (PART #10038 X5) **Main function**: Push and hold the vertical canvas clamp against the Canvas fabric and the Neoprene cellular rubber tape. **Relative importance**: 100 %. If the wheels were absent, the vertical canvas clamp would fall off. **Total importance:** 97 % **Material**: Plastic **Weight:** 265 g	
2.1.3	BOLTS, UNBRAKO ISO 7380 M8X60 (PART #10013 X5) **Main function:** Hold and support the fastening wheels **Relative importance:** 100 %. If the bolts were absent, the wheels would not be connected to the other parts and then fall off. **Total importance:** 97 % **Material:** Stainless steel A2 **Weight:** 95 g	
2.2	HORIZONTAL CANVAS CLAMP **Main function**: Fasten the horizontal canvas to the second panel. **Secondary function:** Seal the horizontal canvas to the second panel. **Secondary function:** Seal the canvas in the corner point of the horizontal and vertical panels **Relative importance:** 97 %. Without this part, some water will be flowing through the fence. **Total importance:** 95 %	
2.2.1	V2100 HORIZONTAL CANVAS CLAMP (PART #10189) **Main function:** hold the canvas and the solid silicone tube **Relative importance:** 100 %. The horizontal canvas clamp (2.2) would be useless without this part **Total importance:** 95 % **Material:** Aluminium 6063-T3 **Weight:** 1500 g	

2.2.2	FASTENING WHEEL M8 (PART #10038 X5) **Main function**: Push and hold the horizontal canvas clamp against the Canvas fabric and the Neoprene cellular rubber tape. **Relative importance**: 90 %. If the wheels were absent, the vertical canvas clamp would easily be displaced. **Total importance:** 86 % **Material**: Plastic **Weight:** 265 g	
2.2.3	BOLTS, UNBRAKO ISO 7380 M8X60 (PART #10013 X5) **Main function:** Hold and support the fastening wheels **Relative importance:** 100 %. If the bolts were absent, the wheels would not be connected to the other parts. **Total importance:** 95 % **Material:** Stainless steel A2 **Weight:** 95 g	
2.2.4	CANVAS LOCK SHEET **Main function:** Seal the canvas in the corner point of the horizontal and vertical panels **Relative importance**: 50 %. The canvas could be sealed without the lock sheet, but not as good. **Total importance:** 48 %	
2.2.4.1	CANVAS LOCK SHEET (PART #10043) **Main function:** Push the solid silicone tube into the vertical plate. **Relative importance:** 100 % **Total importance:** 48 % **Material:** plastic **Weight:** 28 g	
2.2.4.2	SCREWS **Main function:** Fasten the canvas lock sheet to the horizontal canvas bracket. **Relative importance:** 100 % **Total importance:** 48 % **Material:** Stainless steel A2 **Weight:** 10 g	
2.2.5	LATITUDINAL ECCENTRIC LOCK **Main function:** Pull the horizontal canvas clamp (2.2) against the vertical plate. **Relative importance:** 50 %. The horizontal canvas clamp (2.2) would still be able to fulfil most of its functions even without the latitudinal eccentric lock. **Total importance:** 48 %	

2.2.5.1	ECCENTRIC LOCK (PART #10044) **Main function:** Pull the horizontal canvas clamp (2.2) against the vertical plate. **Relative importance:** 100 % **Total importance:** 48 % **Material:** Stainless steel 1.4307 Type 304L **Weight:** 203 g	
2.2.5.2	SCREWS, ISO 10642 M6X8 (PART #10262 X3) **Main function:** Fasten the eccentric lock to the horizontal canvas bracket. **Relative importance:** 100 % **Total importance:** 48 % **Material:** Stainless steel A2 **Weight:** 7 g	
2.3	CANVAS CLAMP HOOK **Main function:** Hold the force from the eccentric lock **Relative importance:** 40 %. The right side connection would still seal fairly good without this hook **Total importance:** 39 %	
2.3.1	CANVAS CLAMP HOOK (PART #10123) **Main function:** Hold the force from the eccentric lock. **Relative importance:** 100 % **Total importance:** 39 % **Material:** Stainless steel A2 **Weight:** 52 g	
2.3.2	SCREW, UNBRAKO ISO 7280 M8X25 (PART #10008) **Main function:** Fasten the canvas clamp hook to the horizontal plate **Relative importance:** 100 % **Total importance:** 39 % **Material:** Stainless steel A2 **Weight:** 11 g	
3.	LONGITUDINAL ECCENTRIC LOCK **Main function:** Pull the first panel against the next one in order to seal between the underlying foam gaskets. **Important:** This part is not considered in the study. **Weight:** 726 g	

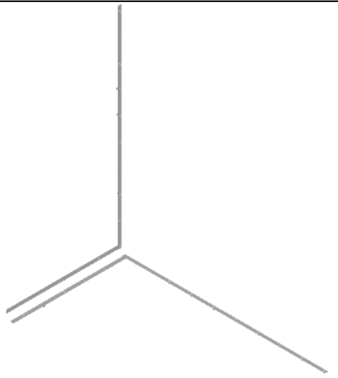
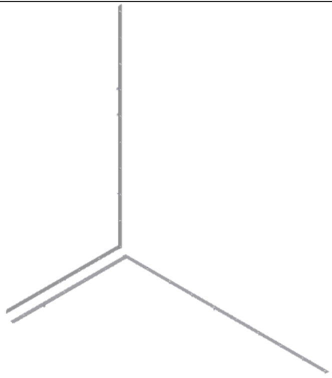
4	LEFT SIDE CONNECTION **Main function**: Fasten the canvas to the plates. **Secondary function**: Seal between the canvas and the plates. **Relative importance**: 100 %. If this connection were absent, the canvas would not be fastened anywhere. **Total importance:** 98 %	
4.1	VERTICAL PLATE: V2100 Canvas bracket Vertical (part #10141) V2100/V1800 Canvas bracket (part #10117) HORIZONTAL PLATE: V2100 Canvas bracket horizontal (part #10118) V2100/V1800 Canvas bracket (part #10117) **Main function:** Seal between the canvas and the plate. **Relative importance:** 45 %. The left side connection (4) could be connected to the plates without the canvas brackets only using Unbrako bolts, but would lead to leakage. **Total importance:** 44 % **Material:** Aluminium 6063-T3 **Weight:** 2204 g	
4.2	VERTICAL PLATE: Unbrako ISO 7380 M8x25 (part #10008 x10) and Unbrako ISO 7380 M8x20 (part #10007 x5) HORIZONTAL PLATE: Unbrako ISO 7380 M8x25 (part #10008 x9) and Unbrako ISO 7380 M8x35 (part #10007 x5) **Main function:** fasten the canvas brackets to the plates. **Relative importance:** 100 % **Total importance:** 98 % **Material:** Stainless steel A2 **Weight:** 329 g	

Table 16: Description of sub-systems and components in current system

The following table shows what parts or components are the most important, and what function they perform.

Total importance	Part	Type of function
98 %	Canvas V2100 (part #10098)	Waterproof, flex
98 %	Screws, Unbrako ISO 7380 M8 (part #10008, #10007)	Fasten
97 %	V2100 Vertical canvas clamp (part #10120)	Fasten, seal
97 %	Fastening wheel M8 (part #10038 x5) (vertical)	Fasten
97 %	Bolts, Unbrako ISO 7380 M8x60 (part #10013 x5)	Support
95 %	V2100 Horizontal Canvas Clamp (part #10189)	Fasten, seal
95 %	Bolts, Unbrako ISO 7380 M8x60 (part #10013 x5)	Support
86 %	Fastening wheel M8 (part #10038 x5)	Fasten
74 %	Solid silicone tube	Hold
59 %	Neoprene Cellular rubber tape (part #100048)	Seal
48 %	Canvas lock sheet (part #10043)	Seal
48 %	Screws, Unbrako ISO 7380 M6x20 (part #10005 x2)	Support
48 %	Eccentric lock (part #10044)	Tighten
48 %	Screws, ISO 10642 M6x8 (part #10262 x3)	Support
44 %	Canvas brackets (part #10141, #10117, #10118)	Seal
39 %	Canvas clamp hook (part #10123)	Support
39 %	Screw, Unbrako ISO 7280 M8x25 (part #10008)	Seal

Table 17: Importance of parts and components in the system

The analysis and the table point out that the most important parts for the system serve functions like fastening and sealing/waterproofing. The function of sealing is also prominent among those parts that are less important for the system, but these parts only deal with the last few percentages of potential water passing through the flood wall. Several parts have a supporting function for other parts.

Today's system consists of 67 parts distributed on 17 different parts.

3.9 Synthesis of demands and requirements

When doing a development project it is necessary to have a framework to work within. This framework is given by the user demand and product requirement specifications described in this section. User demand specifications says what the product should or must do and is based on an assessment of stakeholders and user situations. The product requirement specifications is a transformation of the user demands into technical attributes, and describes how the product should perform (Grave 2013). DfX has had an influence behind the scenes when the specifications have evolved.

3.9.1 User demand specifications

The user demand specifications for the system are described in Table 18. They are grouped by the different stakeholders' demands and needs. The table says what the product could, should and must be.

	Must	Should	Could
AQUAFENCE - COMPANY AND SALES TEAM			
Cheap to produce		X	
Cheap to transport		X	
Low space occupation when stored		X	
Patentable			X
Safe	X		
Sellable	X		
THE MANUFACTURER			
Easy to handle and assemble		X	
Safe to handle	X		
THE TRANSPORTER			
Easy to handle		X	
High transportability		X	
THE PRODUCT OWNER			
Cheap and easy to maintain		X	
Do not leak	X		
Durable and robust	X		
Easy to store		X	
Environmental friendly		X	
Flexible design	X		
High availability	X		
Low initial cost		X	
Low space occupation when stored		X	
Not absorb toxic fluids		X	
Possible to dispose	X		
Quick to install	X		
Reliable	X		
Repairable when in use	X		
Reusable	X		
Tolerate climate exposure (UV-light, contaminated water etc.)	X		
THE INSTALLERS/DISMOUNTERS			
Easy installation/adjustment, independent of height of installer	X		
Easy to inspect if installation is done properly	X		
Error free installation/adjustment	X		
Installation regardless of any predefined sequence		X	
Intuitive installation/adjustment	X		
Low weight		X	
No loose parts		X	
Quick to install/adjust		X	
Safe to install	X		
Tool free installation/adjustment		X	
THE PUBLIC			
Not hinder activities ahead of the flood event		X	
Reliable	X		
Visual appealing		X	

Table 18: User demand specifications

3.9.2 Product requirement specifications

The product requirement specifications that says how the system shall perform are described in Table 19. The table comprises many and narrower specifications, and this is essential in order to fit already existing interfaces (Grave 2013). They are grouped by different kinds of requirements.

	Value	Unit
FUNCTIONAL REQUIREMENTS (PERFORMANCE)		
Water tightness/leakage	< 3.1*	L/min/running meter
Flex: horizontal angular direction	-2.5 - +2.5	degrees
Flex: vertical angular direction	-2.5 - +2.5	degrees
Flex: Longitudinal direction	> 10	cm
Flex: Vertical	> 5	cm
Flex: Latitudinal direction	> 5	cm
AMBIENT REQUIREMENTS		
Corrosion resistant	Yes	
Water tolerance	IPX8	IP code
UV intensity tolerance	> 14	
Operating temperature	-10 - +45	°C
OPERATIONAL REQUIREMENTS		
Possible reuses	>100	times
Installation steps	< 14	steps
Installation time	< 2.5	minutes/connection
Time used to correct errors during installation	< 5	seconds/panel
Availability	99.8	%
Max load in longitudinal direction (pulling panels apart)	200	N
Max force in latitudinal direction (from water)	43.2 **	kN/m
Max pressure on horizontal plate (form water)	20.6	kPa
MAINTENANCE REQUIREMENTS		
Visual inspection interval	1	/use
Frequency of part replacement	< 1	part/100 panels/use
RELIABILITY REQUIREMENTS		
Systems properly installed	> 99.9	%
Task success of the installation steps	> 99.9	%
Adequate distance for visual installation check	< 3	meter
Failures during operation	< 1	/h/2000 panels
SAFETY REQUIREMENTS		
Incidents that require medical treatment	<1	/10 000 panels
DESIGN REQUIREMENTS		
Weight	< 8	kg
Height (when folded)	< 66.5	mm
OTHER REQUIREMENTS		
Highest interaction point above the horizontal plate	200	cm
Number of loose parts	≤ 1	
Number of times persons need to do an installation under surveillance before they can do it unassisted.	1	time

Table 19: Product requirement specifications

**) The leaking water can be handled by regular and cheap water pump. This is normal practice in the industry.*

***) A safety factor of 2 is used.*

3.10 Summary

The case study carried out in Chapter 3 has given an in-depth knowledge about the flood protection system of AquaFence, especially focusing on the connection system. The system has been explained and understood.

The chapter started by introducing the company AquaFence and roughly how the product works. This was relevant to have an understanding of where and in what market AquaFence is operating. The case study continued into a more detailed description of stakeholders of the system. The stakeholders had different concerns, but aspects that recurred were that the safety (in all product life phases), efficiency (in all product life phases), value, appearance, quality, functionality and quickness is important and desirable.

The situation, under which the system is used was described to often be stressful, chaotic or some sort of crisis. Problems and issues occur, and the fastening wheels, the canvas clamps, canvas lock sheet were those parts that turned out to cause the most trouble.

The installation process was scrutinised, and both installation time and system usability was measured. It takes some time to install the system, and the activities that definitely take the most time is the activities of loosening and tightening the fastening wheel. These activities stand alone for 86 % of the system installation time. The system usability score was also poor, giving scores as low as 28. Although the score was low, the section did not say anything about why they were low.

The functional analysis showed that the most important parts in the system cover functions like fastening, sealing and waterproofing. Several parts does not contribute directly to the purpose of the system, but is supporting or enabling other parts to achieve their purpose. The eccentric lock was a part that had a fairly low importance for the system.

The assessment of functionality, stakeholders, user situation and issues, together with the functional analysis formed a set of user demand specifications that said what the product should or must do. The demands were grouped according to stakeholders, and the stakeholders with the most demands related to them were the product owner and the installers. The user demands were furthermore transformed into technical performance attributes in a product requirement specification. Functional and operational requirements where the most prominent requirements.

With all the input collected in this case study, indications for further elaboration have arisen. What turns out to be the most important aspects in the system is the water tightness, the ease of connection and time consumption. These aspects should be addressed in order to increase the value, and parts that should be especially examined are the fastening wheels, canvas clamps and canvas lock sheet. These considerations will be taken further in the action research in Chapter 4.

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4 Action Research: Development and Design for a New Improved System

As previously mentioned, one of the objectives of this thesis is to develop an improved design of AquaFence' flood protection system that has additional value, and this should be done in a holistic perspective. In the previous chapter, a case study focusing on the current flood protection system was carried out. The study provided an in-depth knowledge and useful indications for further development that will be elaborated on in this chapter, in the form of an action research.

This chapter is considered an *action research* because the research takes place in a real-world situation, and the aim is to solve a real problem. Also because decision-makers in AquaFence is aware of problems with the current system, but lack requisite methodological knowledge to deal with it (O'Brien 1998). The action research takes the form of an *evaluation research* since the purpose is to examine the system and the outcomes associated with a particular solution to the problems (Center for Innovation in Research and Teaching 2012). Additionally is the study *prescriptive*, primarily dealing with the question of how the system should be (Van der Voordt and Lans 2002).

In similarity with the case study carried out in Chapter 3, this chapter and action research comprises several stages and is framed based on phases from the value study job plan.

Phase III, which is the creative phase generating ideas and identifying other ways to perform the product's functions (SAVE International 2007), consists of concept development. The idea generation process is described and a number of possible solutions are presented. Phase IV, the evaluation phase, consist of a weighting of the evaluation criteria and screening of all the suggested concepts. Phase III and IV in the value analysis job plan correspond to the IPM model phase 3, concept development.

After a concept is selected, this new concept is developed and presented in details as part of the job plan phase V - development, and IPM phase 4 - structure and design.

The chapter ends with a verification section where the new system in tested for installation time, installations errors and usability. Also fulfilment of demands and requirements, compliance with problems, applied DfX guidelines and compatibility with other systems are described.

A visualisation of the chapter and study research scope is provided in Table 20.

<table>
<tr><th>Value Analysis</th><th>Job plan phases</th><th>Section</th><th></th><th>IPM phase</th><th></th></tr>
<tr><td rowspan="4">Value Workshop</td><td>Phase III – Creative</td><td>4.1 - Concept development</td><td rowspan="4">DfX Applied</td><td rowspan="2">Phase 3 – concept development</td><td rowspan="3">Action research</td></tr>
<tr><td>Phase IV – Evaluation</td><td>4.2 - Concept evaluation and selection</td></tr>
<tr><td rowspan="2">Phase V - Development</td><td>4.3 - Presentation of the new system</td><td>Phase 4 – Structure and design</td></tr>
<tr><td>4.4 - Verification</td><td colspan="2"></td></tr>
</table>

Table 20: Visualisation of Chapter 4 and action research scope

4.1 Concept development

The purpose of concept development is to find new solutions and to end up with a well-considered concept with a great potential (Grave 2013).

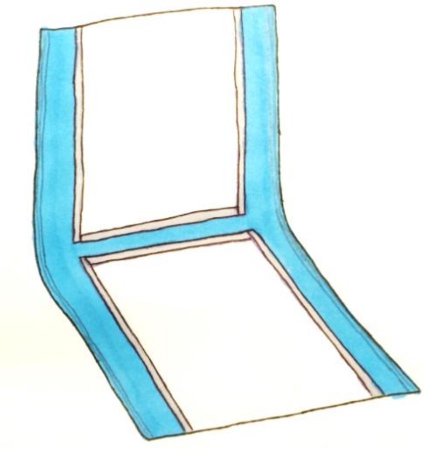
The case study in Chapter 3 gave real-life input in form of a review of stakeholders [3.4], user situations [3.5], problems and issues [3.6], installation time and usability [3.7], a functional analysis [3.8], user demand specifications [3.10.1] and product requirement specifications [3.10.2]. In addition to this, Section 2.3 about design for X provided theories about good design concerning quality, cost, environment, safety, maintainability, reliability, manufacturability, assemblability, transportability, usability and recyclability.

With these inputs and aspects as a framework, a creative process to create concepts was initiated. During this process, several concept generating methods from the IPM model phase 2 were used. Analogue markets were explored and solutions were sought after both internally and externally. A problem based search for solutions was used together with structural variations and the principle of orthogonal concepts.

4.1.1 Fundamental concepts

The development process brought up a lot of different concepts, and they can all be divided into three main concepts:

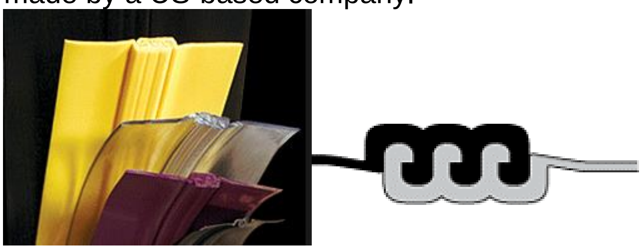
- **Single lip connection**. This is like today's solution. PVC Canvas is permanently attached to one panel and is connected to the next panel with some kind of temporary attachment method.
- **Double lip connection**. PVC Canvas is permanently attached at both sides of a panel and forms symmetry. The canvas from one panel is temporary connected directly to the canvas from the other panel.
- **No lip connection.** There is no PVC canvas attached on the sides of the panel. The panels are connected directly to each other.

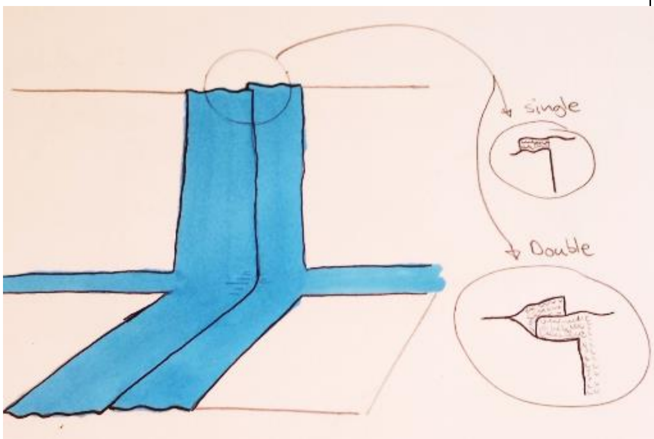
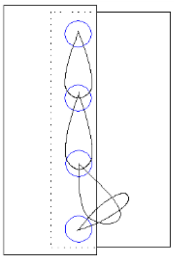


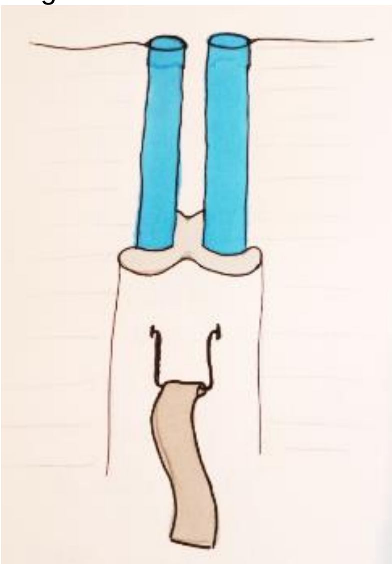
Picture 15: Double lip connection

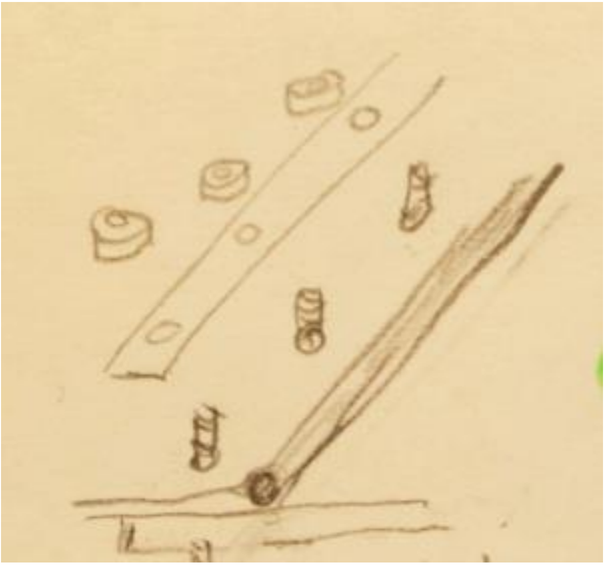
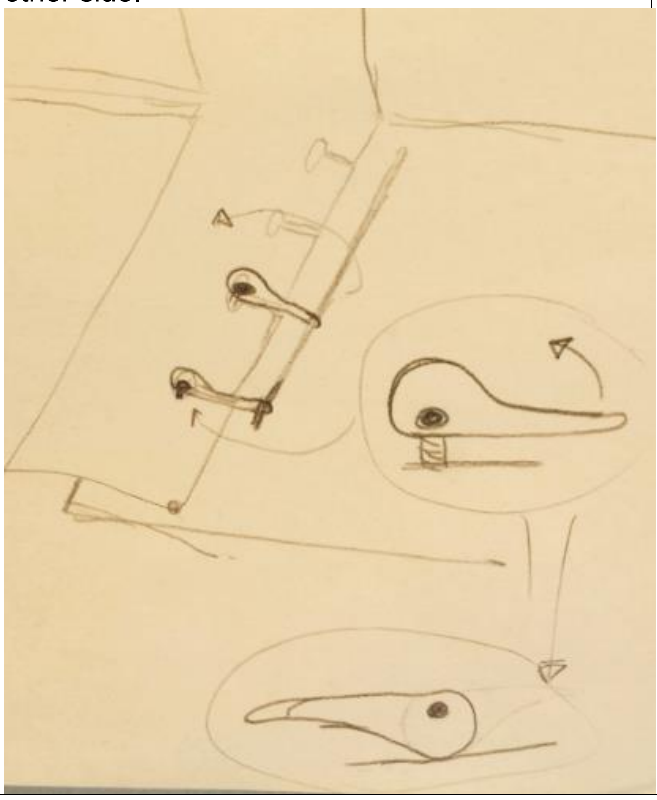
4.1.2 Possible solutions

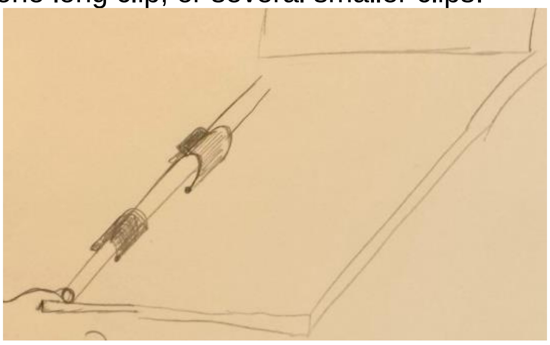
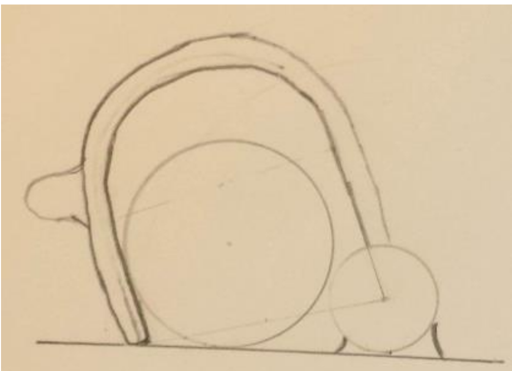
After at creative and thorough development process, 30 different possible conceptual solutions were found. They are all presented in Table 21, but are not arranged in any specific order other than presenting double lip concepts first, then single lip concepts and in the end no lip concepts. The column '*Name and sketches or pictures'* contains very rough sketches and a description of how the concept works. The issue of sealing in the corner between the panels is of high importance and has therefore a separate column with a suggested solution for the corner. *'Pros'* and *'Cons'* are comments on whether the suggested concept is good or poor.

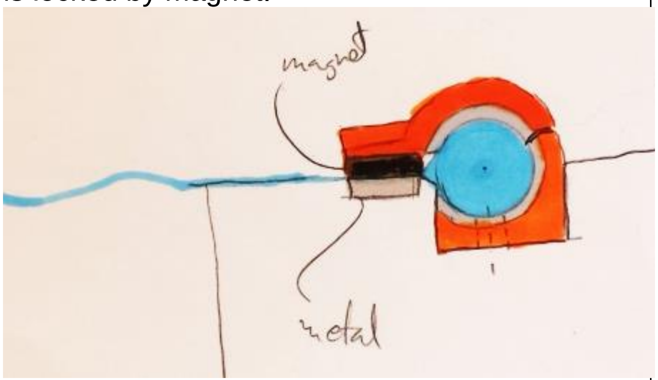
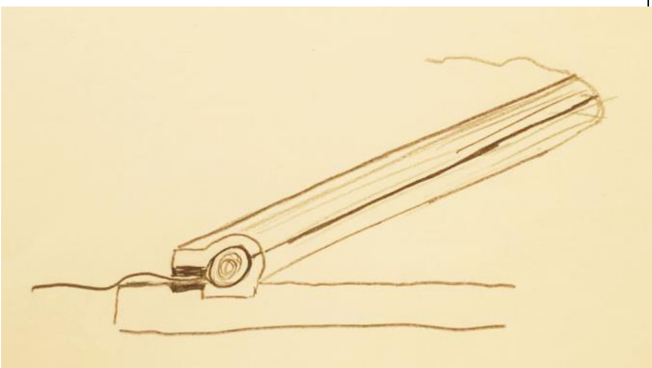
	Name and sketches or pictures	Solution for corner	Pros	Cons
Double lip	A – WATERTIGHT ZIPPER  *Picture 16: YKK Aquaseal - Source: ykkfastening.com*	Not needed	Very fast and easy. Cheap. No corner push needed.	Vulnerable for sand dirt. Vulnerable for people stepping on it.
	B – DOUBLE ZIPPER Same principle as A, but with an extra robust zipper (not necessarily watertight) to protect the first one from dirt.	Not needed	Less vulnerable to dirt than solution A.	Increasing number of parts. Uncertain if the extra zipper will have effect.
	C – TRIPLE ZIPPER Same principle as B, but with two extra protecting zippers.	Not needed		A lot of parts.
	D - MAXIGRIP (MX53) Two canvas lips are connected with Maxigrip. Maxigrip is a waterproof zipper-like closure mechanism much less vulnerable to sand and dirt than regular zippers. It comes with a roller and is made by a US-based company.  *Picture 17: MX53 - Source: itwmaxigrip.com*	Not needed	Very fast and easy. More robust to sand and dirt than regular zippers.	Should be lubricated before use. Uncertain how much bending it tolerates.
	E – MAGNET STRIP Two canvas lips are connected to each other with one magnet strip on each of the lips.	Not needed	Intuitive and fast.	Entire part needs to be replaced if it is damaged. Required holding force could be expensive. Metal things will stick to it.

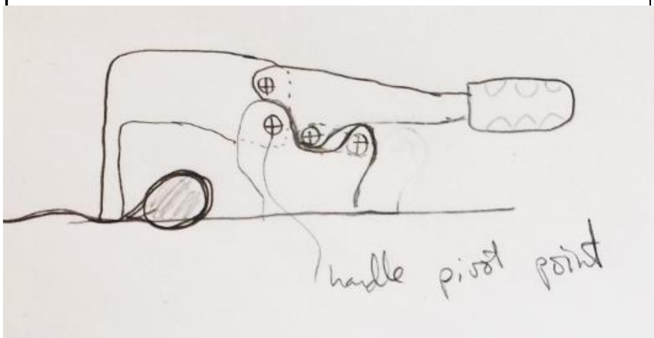
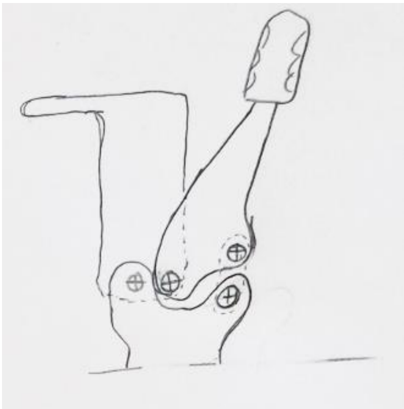
	F –VELCRO Two canvas lips are connected by a full length heavy duty velcro. The connection can be either single or double. A double connection will be more watertight and robust, but requires more work from the installer.  	Not needed	Easy and intuitive. Cheap. Fast. No mechanics.	Water tightness Is low. It could be difficult to connect the vertical part 100 % if you do not have someone on the backside to withstand the pushing force the installer applies. Small particles will accumulate in the Velcro and reduce the effect.
	G – DOUBLE VELCRO Same solution as F, but with an extra flap.	Not needed	More robust than a single Velcro.	More parts to assemble.
	H – DUTCH LACING Dutch lacing has earlier been used both in jackets and in tents. One of the PVC lips has holes while the other has loops. The loops are thread into the hole and through the loop of the previous loop.  *Picture 18: Dutch lacing - Source: songofthepaddle.co.uk*	Not needed	Cheap.	Not intuitive. Not watertight. Time consuming.
	I – ROLL AND CLIP This is a very simple concept. You just roll the canvas together and put a clip on it to hold.  *Picture 19: Roll and clip - Source: trysmallthings.com*	Not needed	Easy. Cheap.	Has an amateur look. Extra parts needed. Time consuming.

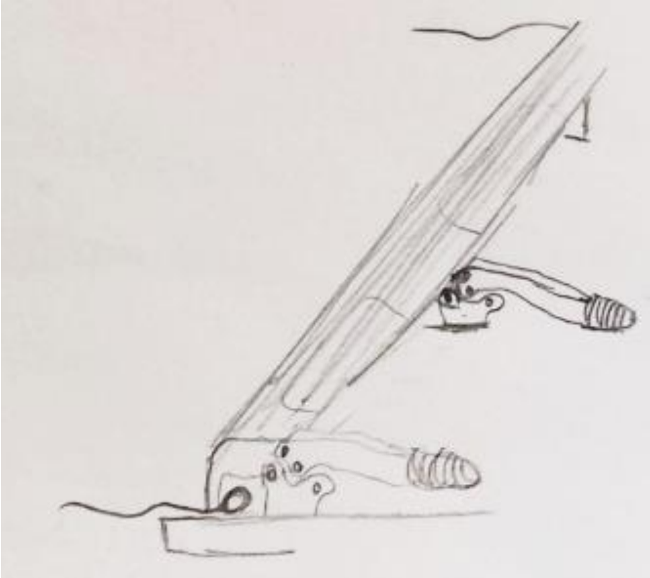
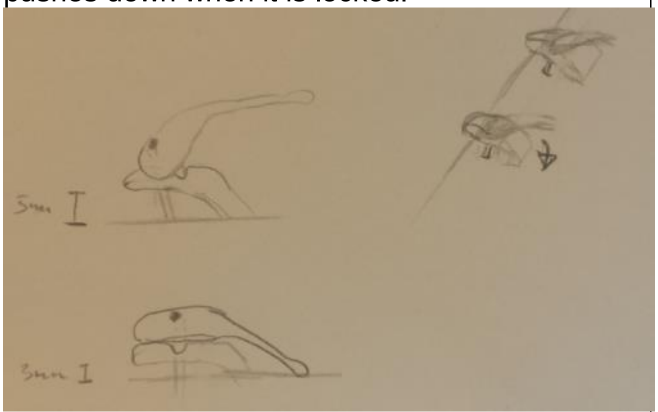
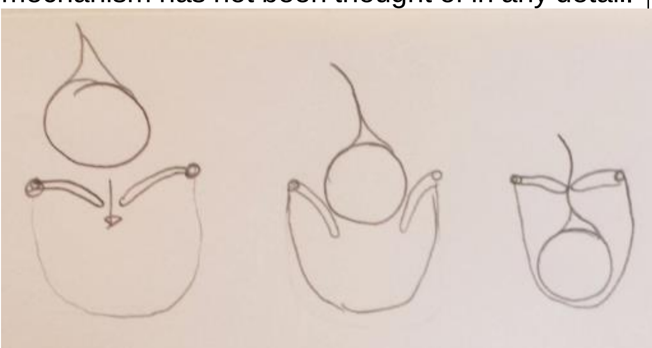
	J – MID SLIDER A slider with two jaws connects two PVC canvas lips together. The mid slider is made of some kind of plastic or foam material. The installer goes from panel to panel with a bundle of these 2.4 m long sliders. 	Not needed	Quick. Intuitive.	Additional loose part. Uncertain about water tightness and the need for lubrication.
	K – MID SLIDER INVERSE (CANVAS) This solution is similar to J, but now the jaws are attached to the canvas lips instead of the slider. The slider will be a string of canvas that is threaded into the canvas lip jaws.	Not needed	Quick. Intuitive.	Additional loose part. Uncertain about water tightness and the need for lubrication.
	L – BUTTONS Just regular buttons connecting the canvas lips together.	Not needed	Intuitive. Cheap.	Takes some time. Low water tightness
	M – RAPIDAM ZIPPER This is a patented zippers used at flood protection system Rapidam by Floodgurads. It has some similarities to solution D Maxigrip  *Picture 20: Rapidam zipper - Source: [youtube.com]*	Not needed	Intuitive. Easy.	It is patented by a competitor.

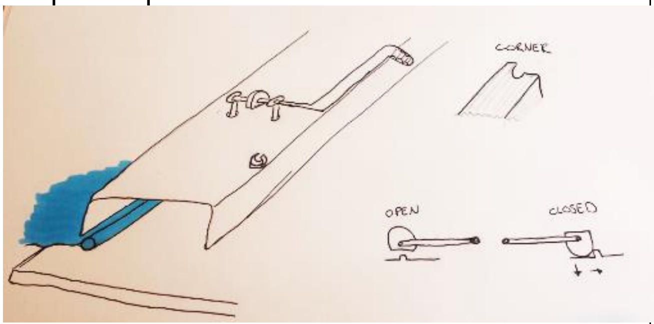
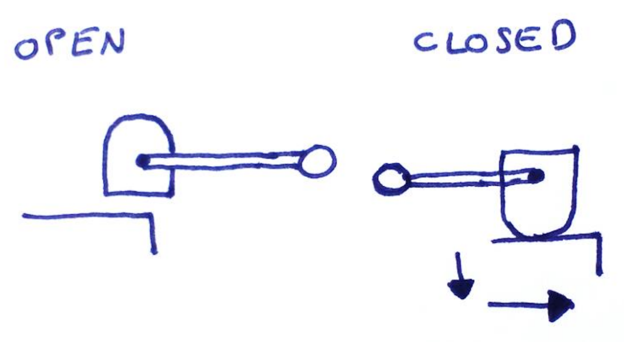
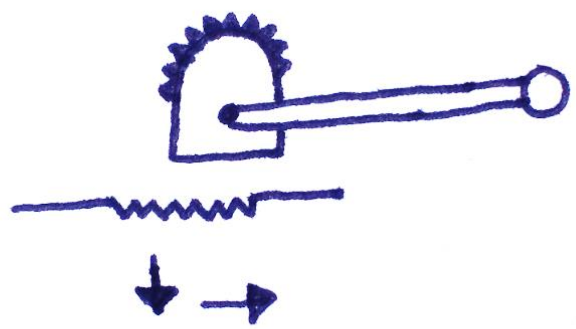
Single Lip	N – HOLES PLUS RAIL This is a single lip solution where the PVC canvas has several holes along the lip. The panel on the other side has the same amount of threaded bolts. The canvas is placed onto the bolts and secured with an aluminium rail (canvas bracket) and nuts. 	The length of the aluminium rail is extended so that it pushes all the way into the corner.	Robust. Reliable.	Time consuming. A lot of loose parts. Addition tools is required.
	O – OPEN HOLES WITH CLAMP Several cuts are made normal to the canvas lip. When connecting, the canvas is slid under the cam levers that are placed on the panel on the other side. 	Plug*		Very uncertain with the water tightness. No so intuitive.

	P – CLOSED HOLES WITH CLAMP This solution is inspired by kitchen cabinet hinges (IKEA part called Utrusta). The hinge-like structure is permanently connected to the panel. The canvas on the other side has holes that can be slid over the hinges. After this is done, the hinges are folded and seals around all the holes. 	Plug*	Innovative. Fast.	Many parts with a lot of details. Uncertain about the water tightness.
	Q – OVERCLIP The concept for this one is that the grabbing clips are permanently connected to the panel with hinge joints. These clips grab over the silicone tube in the canvas and locks. It could be either one long clip, or several smaller clips.  *Picture 21: Two smaller clips grabbing over the silicone tube.*  *Picture 22: Side view of the clip and the silicone tube.*	Plug* /slide-block**	Intuitive. Easy.	Might break if one step on it. May easily open.

	R – MAGNET GRABBER This concept is inspired by P-clamps, but a bit modified.  *Picture 23: P-clamps - Source: amphenolpcd.com* The clamp clamps around the silicone tube and is locked by magnet.  *Picture 24: The clamp is screwed down into a groove in the panel.*  *Picture 25: The clamp goes all the way along the edge of the panel.*	Swing-block***	Easy. Intuitive. Fast.	The clamp can break if it is stepped upon.

	S – GRABBING CLAMP This is a modified horizontal acting toggle clamp  *Picture 26: GN 820-NI toggle clamp – Source: jwwinco.com* The concept is that the clamp grabs over and pushes down the canvas.   *Picture 27: Toggle clamp in open position* Instead of having several individual toggle clamps, they can be linked together via a full length canvas clamp.	Plug*	Powerful. Easy.	A lot of kinematics/ mechanics that can fail.

	 *Picture 28: Toggle clamps connected via a full length canvas clamp*			
	T – BITE The concept here is similar to O, but has another type of clamp, and there are no cuts in the canvas. The clamp bites over the canvas, and pushes down when it is locked. 	Slide-block**	Easy.	Uncertain about water tightness. If you do not, start the right place when installing you will have to redo.
	U – SWALLOW This solution works like a one way swinging door. The canvas silicone tube in its full length is pushed into the groove, but cannot be pulled out before clutch mechanism is released. This mechanism has not been thought of in any detail. 	Plug*/ Swing-block***	Discrete design. Intuitive. Easy.	Small parts and fine mechanics. Could jam if dirty. Needs a mechanism for releasing the silicone tube.

<table>
<tr>
<td></td>
<td>X – PUSH TAP
This concept is quite similar to today’s solution. The canvas clamp is still there, but the difference is that you also have an eccentric cam lever that pushes downwards and inwards at the same time. The inward push comes from the contact between the cam lever and a pin coming from the canvas clamp. The corner is a modification of today’s canvas lock sheet. Several levers can be coupled in parallel.

</td>
<td>Current solution</td>
<td>Intuitive.
Robust.
Few movements.</td>
<td>The horizontal part must be fastened before the vertical.</td>
</tr>
<tr>
<td></td>
<td>V – PUSH FRICTION
This is the same concept as X, but the inward push comes from the friction between the cam lever and the canvas clamp itself.

</td>
<td>Current solution</td>
<td>Intuitive.
Robust.
Few movements.</td>
<td>Might slip when wet.
No weight reduction.</td>
</tr>
<tr>
<td></td>
<td>W – PUSH COG WHEEL
This is the same concept as X, but the inward push comes from the contact between teeth at the cam lever and teeth at the canvas clamp.
</td>
<td>Current solution</td>
<td>Intuitive.
Robust.
Few movements.</td>
<td>Uncertain if it will handle the geometry constraints.</td>
</tr>
</table>

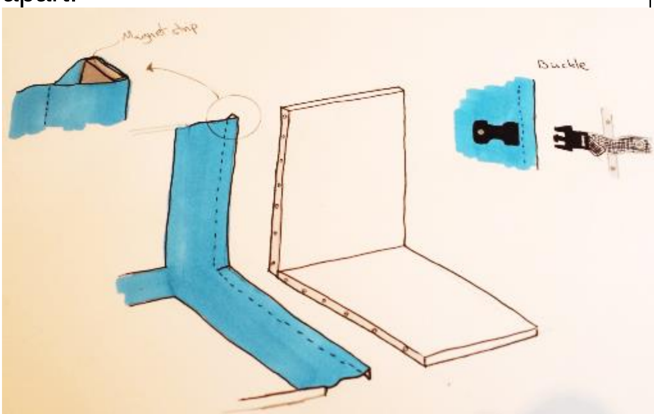
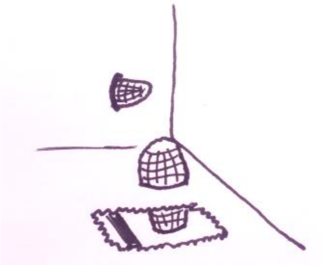
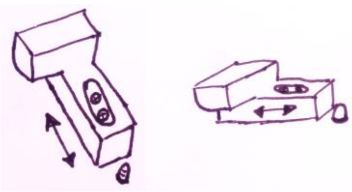
	Y – PUSH HANDLE A handle is connected to a bolt and to the canvas clamp with a revolute joint. When the handle is pushed down, the canvas clamp is pushed downwards and inwards. 	Current solution	Easy. Intuitive. Tight connection	Very tall in open position.
	Z – ECCENTRIC PULL This concept is quite similar to today's solution. The exception is that the fastening wheels are replaced by one or several eccentric locks. When a hook and an eccentric lock are installed at different elevations, the lock will push both inwards and downwards at the same time.	Current solution	Tight connection.	
	AA – MAGNET SNAP + STRAP A metal rail is attached to the left side of the panel. A magnetic strip is glued and sewed into the canvas which is permanently attached to the right side of the panel. The Canvas will then snap on to the next panel when installed. One (or more) plastic buckles connects the canvas and the panel as a safety so that they are not pulled apart. 	Not needed	Easy to connect. Fun.	Vulnerable to sand when installed.
No lip	AB – MULTIPLE ECCENTRIC LOCK The horizontal plate is connected to the next panel directly through several eccentric locks. The same goes for the vertical plate.	Not needed	Tight connection	No flex/adjustment possible.
	AC – MAGNET Similar to concept AD, but there will be no canvas. The magnet and metal strips are fastened directly to the sides of their respectively panels.	Not needed	No extra parts.	No flex/adjustment possible. High possibility for leakage if it is installed skewed.
	AD –PLUG AND SOCKET The right panel has heightened ridges or plugs pointing out while the left panel has a geometry with the same number of sockets or grooves.	Not needed	No extra parts	No flex/adjustment possible.

Table 21: Possible new solutions

*) *‘Knobs’* is one of the solutions for sealing in the corner between the panels. Concave rubber plugs are fastened permanently to the plates. The canvas is threaded on top of the plugs and will seal a little.



**) *‘Slide block’* is a second way to seal in the corner. A sliding block can be pushed against the canvas and the vertical plate. The silicone tube will be pushed under and ahead of the protruding part the block. A little metal knob is spring loaded and will pop out when the block is slid.



***) *‘Swing block’* consists of the same block as the slide block, but instead of sliding, it will swing counter clockwise from right to left.

4.1.3 Morphological box

A morphological box is a method to systemise solutions based on functions and describes how a product is built up (Grave 2013). The morphological box in Figure 11 shows how different solutions to different functions are combined to form concepts. Selected functions are shown to the left while selected solutions are shown to the right. Different lines represent how each concept is a combination of different solutions. The figure only shows 10 out of 30 concepts.

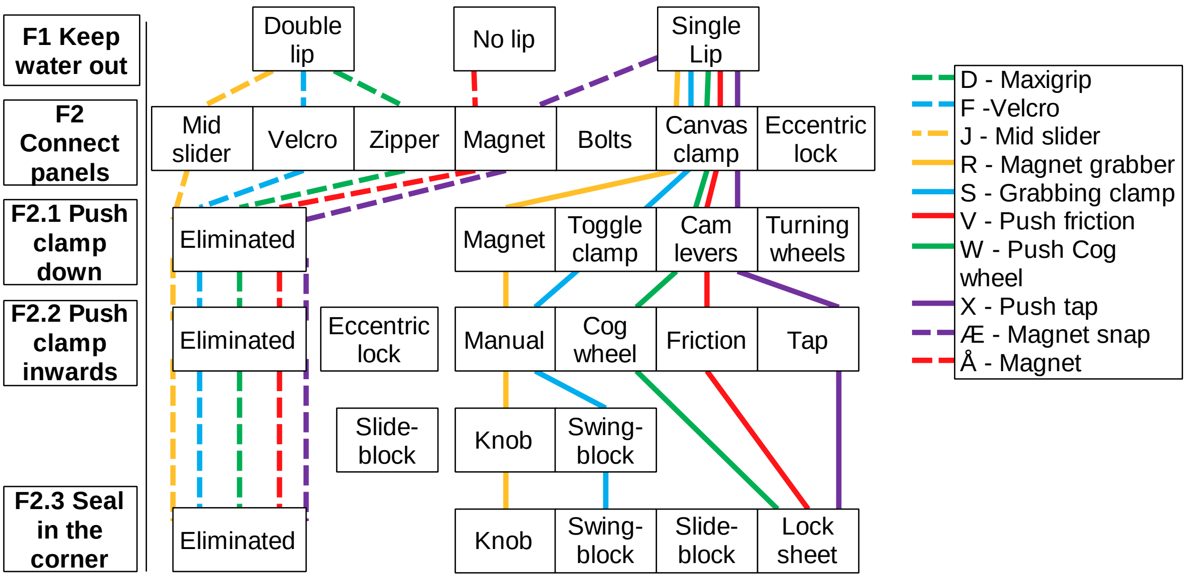


Figure 11: Morphological box of ten different concepts

4.2 Concept evaluation and selection

The previous section generated a huge number of possible new solutions. When having such amount of different concepts, the IPM model's phase 3 suggest to use an evaluation matrix to compare the different concepts based on selected evaluation criteria, in order to find the one with greatest potential (Grave 2013).

The criteria selected to evaluate the concepts against are the different DfX categories. In this way, it is likely that the final concept has high scores regarding several aspects of life phases and virtues.

Some criteria have a higher priority than other, an one way to determine the weight distribution of the different evaluation criteria is to us a pairwise comparison (Salustri 2005)

4.2.1 Weighting

By using pairwise comparison between the different DfX categories, a weighting is established. The result, showing that reliability, safety and quality are the aspects that should be weighted the most, is shown in Table 22. The table also shows which DfX criteria that are more important than the others. '2' means that the criteria listed in the left column is more important than those listed in the top row. '1' means that they are equally important, while '0' means they are less important.

		DfX virtue						DfX life phase						
		Quality	Cost	Environment	Safety	Maintainability	Reliability	Manufacturability	Assemblability	Transportability	Usability	Recyclability	Sum	Normalised sum
DfX virtue	Quality	-	2	2	1	2	1	2	2	2	1	2	17	15
	Cost	0	-	2	0	2	0	2	2	2	0	2	12	11
	Environment	0	0	-	0	0	0	0	0	0	0	2	2	2
	Safety	1	2	2	-	2	1	2	2	2	2	2	18	16
	Maintainability	0	0	2	0	-	0	1	1	1	0	2	7	6
	Reliability	1	2	2	1	2	-	2	2	2	2	2	18	16
DfX life phase	Manufacturability	0	0	2	0	1	0	-	2	1	0	2	8	7
	Assemblability	0	0	2	0	1	0	0	-	1	0	2	6	5
	Transportability	0	0	2	0	1	0	1	1	-	0	1	6	5
	Usability	1	2	2	0	0	0	2	2	2	-	2	13	12
	Recyclability	0	0	0	0	2	0	0	0	1	0	-	3	3
	Sum												110	100

Table 22: Weighting table for different DfX criteria

The pairwise comparison is based on dialogue with AquaFence representatives (Jumburgs 2015).

To recall what the different DfX criteria imply, a short description is provided in Table 23.

Quality	That the product is robust, durable, reliable and has high performance. The degree to which the characteristics of the product meets the given requirements.
Cost	That the cost for AquaFence related to product, process or resources are as low as possible.
Environment	That the environmental impact from the product, the production processes or the materials is as low as possible
Safety	That the product is safe to produce, transport, use and recycle.
Maintainability	That maintenance of the product is easy and cheap.
Reliability	That the product as often as possible perform its function without failing.
Manufacturability	That the product is as easy and cheap to manufacture as possible.
Assemblability	That the product is as easy and cheap to assemble (in the production) as possible.
Transportability	That the product is easy and cheap to transport.
Usability	That the product is easy, effective, efficient to use and that the user is satisfied when interacting with a product.
Recyclability	That the product is easy and cheap to recycle.

Table 23: Short explanation of different criteria. Based on theory from Section 2.3.

4.2.2 Evaluation matrix

When the distribution in the weighting is set, points for each concept can be assigned to evaluate how good or poor the design of the concept is related to the different DfX criteria. The scale goes from 0 to 6, and ranges from extremely poor, very poor, poor, mediocre, good, very good to extremely good. The points assigned are then multiplied with the weight and summarised.

Some concepts involve a lot of uncertainty, and each concept has therefore been given an uncertainty score. The scale for uncertainty goes from 0 to 4, and ranges from no uncertainty (100 %), little uncertainty (95 %), some uncertainty (90 %), great uncertainty (85 %) to very great uncertainty (80 %). The percentage is multiplied with the weighted sum for each concept and gives a total score shown in Table 24.

		Selection criteria													
		Quality	Cost	Environment	Safety	Maintainability	Reliability	Manufacturability	Assemblability	Transportability	Usability	Recyclability	Uncertainty	Sum	**Total score**
Concept	Weight:	15	11	2	16	6	16	7	5	5	12	3			
2x Velcro	G	5.0	4.5	5.0	5.0	5.0	4.5	5.0	4.5	5.0	4.5	5.0	0.00	53	**478**
		77	49	9	82	32	74	36	25	27	53	14	1.00	478	
Push tap	X	5.0	3.5	5.0	5.0	5.0	4.5	5.0	5.0	5.0	5.0	4.5	0.00	53	**474**
		77	38	9	82	32	74	36	27	27	59	12	1.00	474	
Velcro	F	4.0	5.0	5.0	5.0	5.0	4.0	5.0	5.0	5.0	5.0	5.0	0.00	53	**468**
		62	55	9	82	32	65	36	27	27	59	14	1.00	468	
Mid slider	J	5.0	5.0	5.0	5.0	3.5	5.0	5.0	5.0	4.0	5.0	5.0	1.00	53	**461**
		77	55	9	82	22	82	36	27	22	59	14	0.95	485	
Push friction	V	5.0	3.5	5.0	5.0	5.0	3.5	5.0	5.0	5.0	5.0	4.5	0.00	52	**458**
		77	38	9	82	32	57	36	27	27	59	12	1.00	458	
Push cogwheel	W	5.0	3.5	5.0	5.0	5.0	3.5	5.0	5.0	5.0	5.0	4.5	0.00	52	**458**
		77	38	9	82	32	57	36	27	27	59	12	1.00	458	
Maxigrip	D	5.0	4.0	5.0	5.0	4.5	4.0	5.0	5.0	3.5	6.0	5.0	1.00	52	**450**
		77	44	9	82	29	65	36	27	19	71	14	0.95	473	
Magnet snap	AA	4.5	5.0	5.0	5.0	3.5	4.0	5.0	5.0	5.0	5.5	5.0	1.00	53	**449**
		70	55	9	82	22	65	36	27	27	65	14	0.95	472	

Table 24: Evaluation matrix with the eight best concepts.

Table 24 only includes the eight concepts with highest scores. The remaining concepts and calculations can be found in Appendix 8.7. Concept V and W are variations of concept X.

The results from the evaluation matrix where presented for the AquaFence management and the decision taken was to proceed with concept X, the single lip ‘Push tap’ concept.

4.3 Presentation of the new system

Based on the case study in Chapter 3, several potential new concepts were developed in Section 4.1 and the concept X was selected in Section 4.2 as the desired concept to elaborate on. This section presents that concept in more detail.

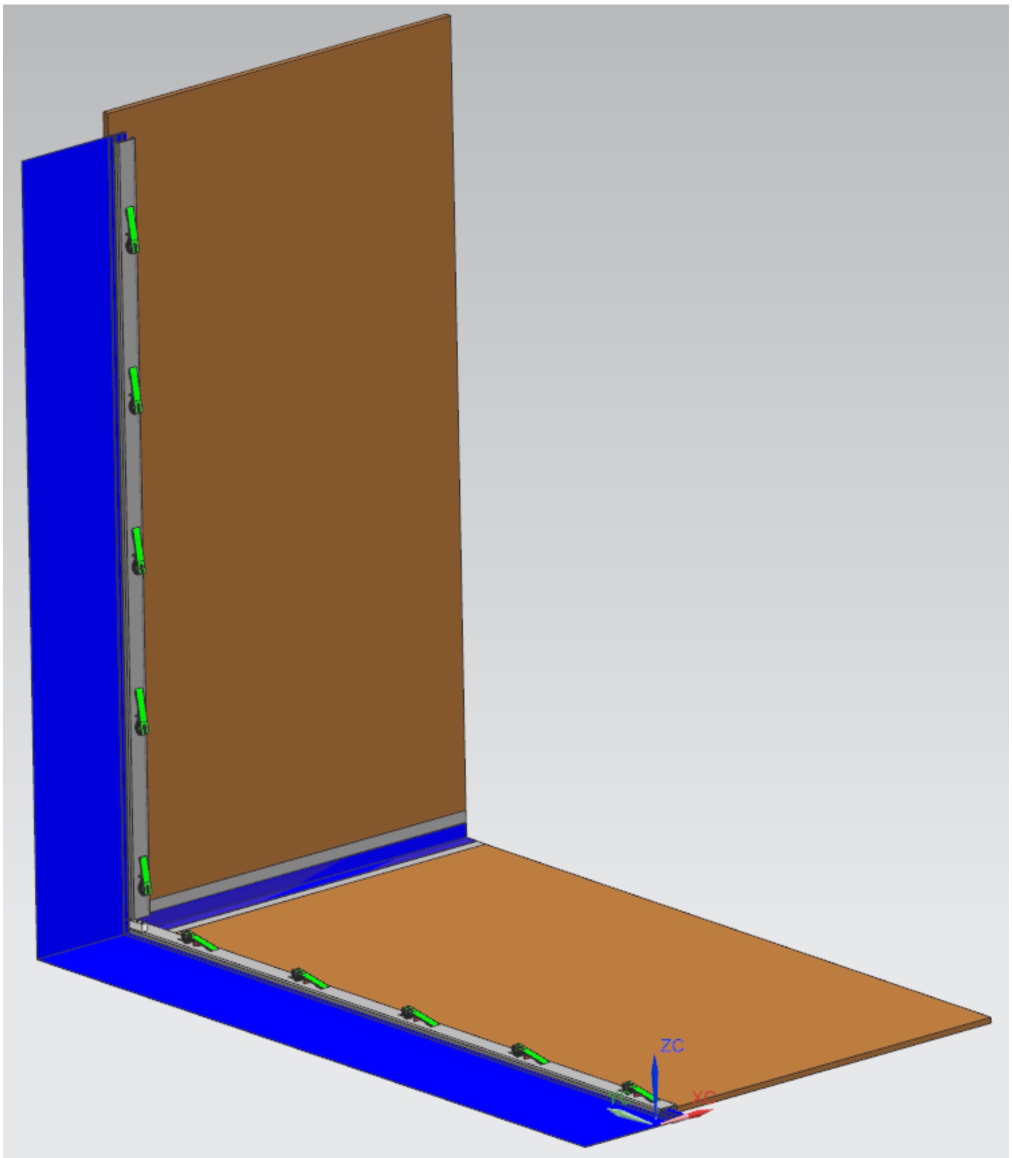
When continuing with the product, the process enters the fifth value analysis phase, the development phase, and phase 4 in the IPM model where structure and design comes to an end.

The transformation of concept X from the conceptual fundament described in 4.1.2, and to the detailed description later in this section has involved several processes. When elaborating on the conceptual fundament presented, design guidelines from DfX, results from the functional analysis and product specifications have strongly influenced the work. Several sketches and CAD-models have been made (Appendix 8.8), calculations have been done, and fine tuning has taken place. Also the method of functional face variation has taken place by varying numbers, placement, geometry or dimensions of elements. The described solution attempts to eliminate all possible user errors and malfunctions.

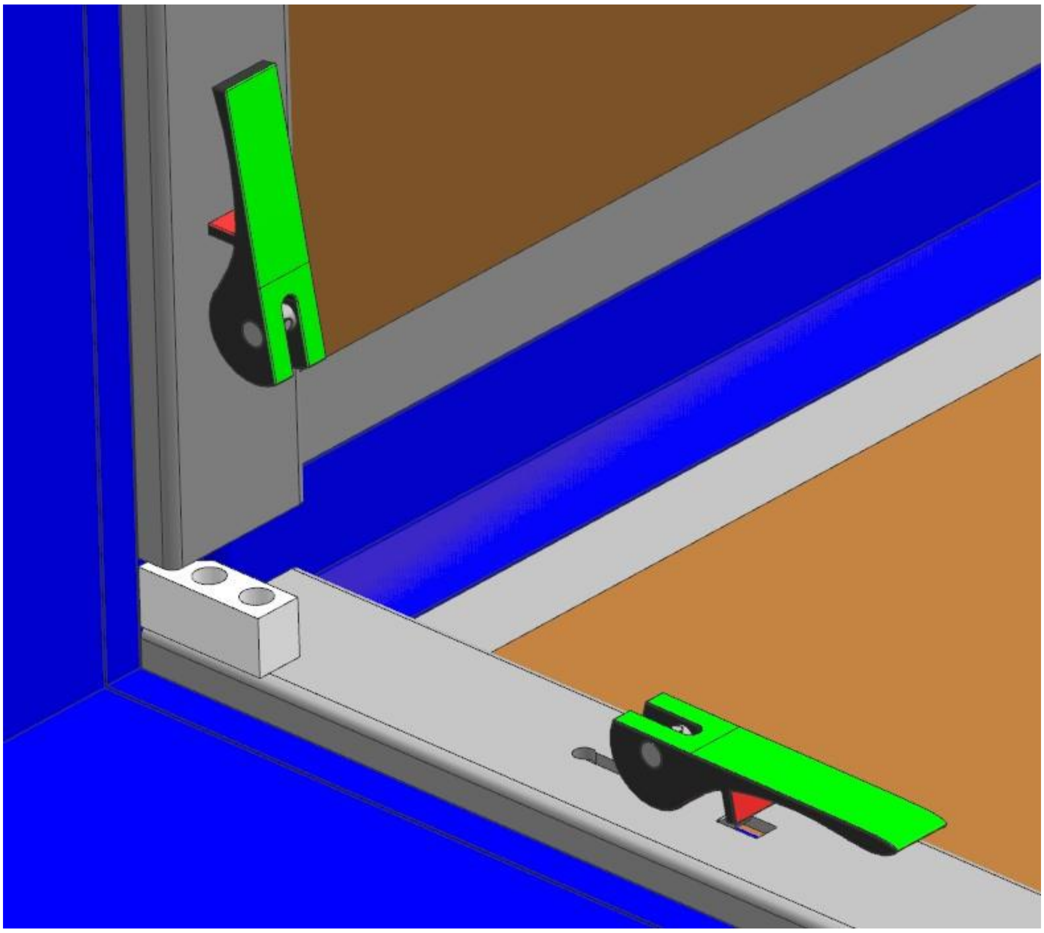
The rest of this section starts by a description of how the new system works. Furthermore are differences between the current and the new system, in terms of physical components, described. After that comes a detailed description of all the new parts, and the end provides a morphological box with the selected solutions.

4.3.1 Functionality

The new system (Picture 29) does not look very unlike the current one, and the main functions are ensured. If the functional analysis of the current system in 3.8 is compared with the new system, it is seen that also the new system solves the functions of physically connecting the panels together and keeping water on the wet side of the fence. The blue canvas keeps the connection waterproof and enables angular and longitudinal flex, and the right side connection fastens and seals the canvas from the first panel to the second one. The major difference between the current and the new system is that the fastening wheels are replaced by fast and intuitive cam lever locks (Picture 30), but there are also several minor adjustments.



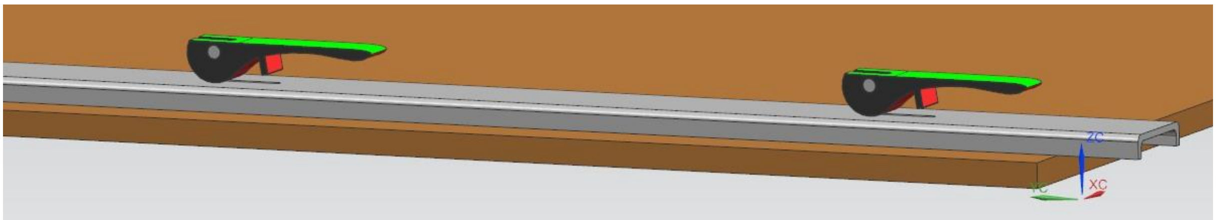
Picture 29: The new system



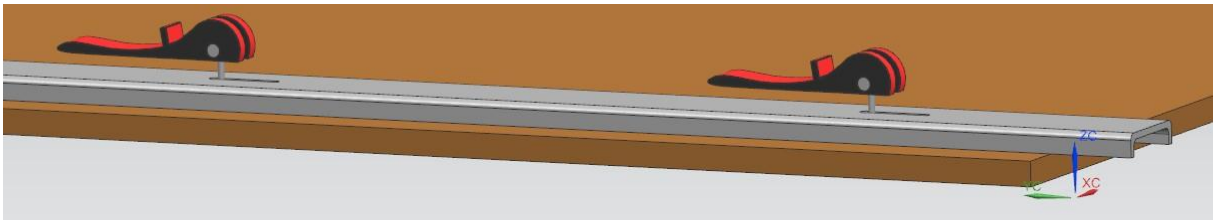
Picture 30: The new cam lever locks

INSTALLATION OF THE PANEL

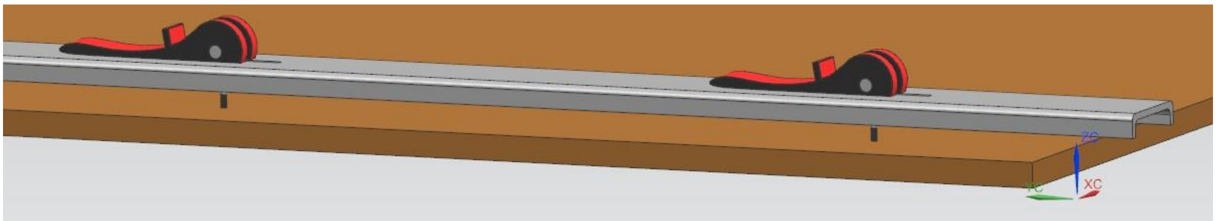
The sequence of pictures 31 - 37 shows how canvas from one panel is connected and fastened by the canvas clamp and cam levers on a second panel.



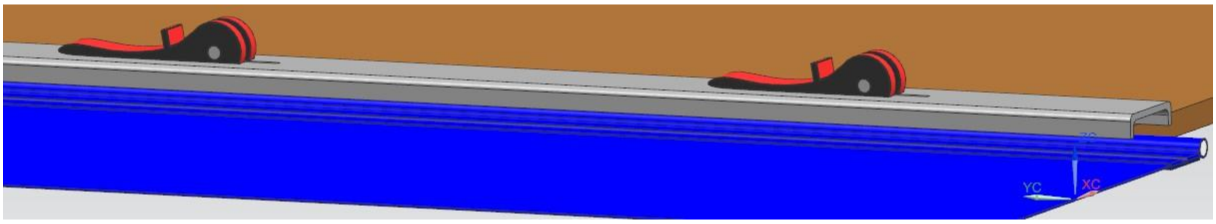
Picture 31: Starting position when starting the installation. The cam levers are locked and the canvas clamp is in lower position. The clearance between lever and canvas clamp is 2 mm.



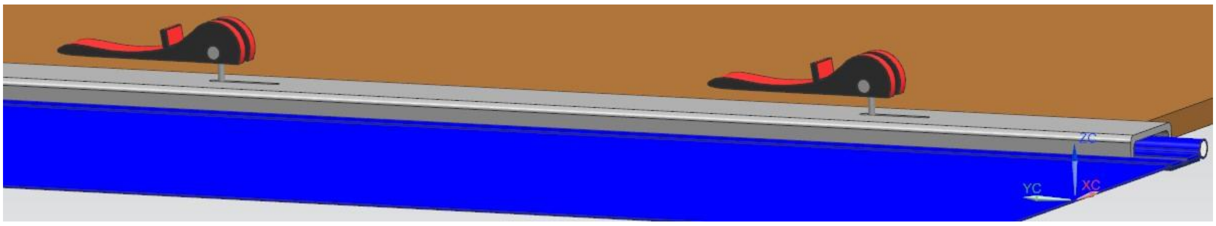
Picture 32: The cam levers locks are opened. The clearance between cam lever and canvas clamp is 14 mm



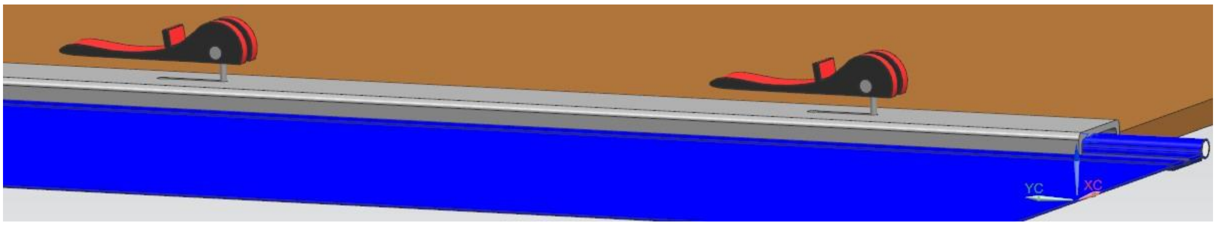
Picture 33: The canvas clamp is lifted 14 mm up. Clearance between lever and canvas clamp is 0 mm



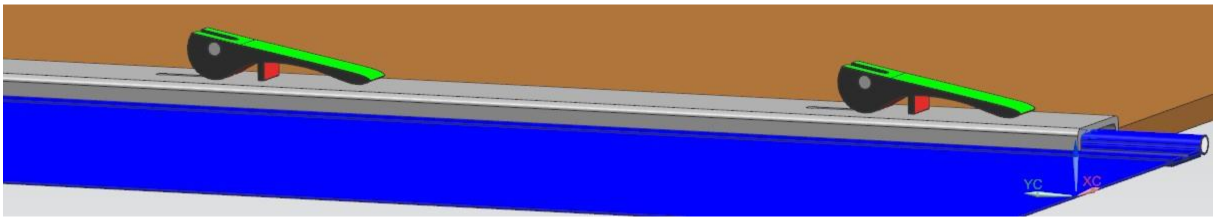
Picture 34: The canvas is fed underneath the canvas clamp.



Picture 35: The canvas clamp falls down and the clearance between the cam lever and the canvas clamp is approximately 10 mm.



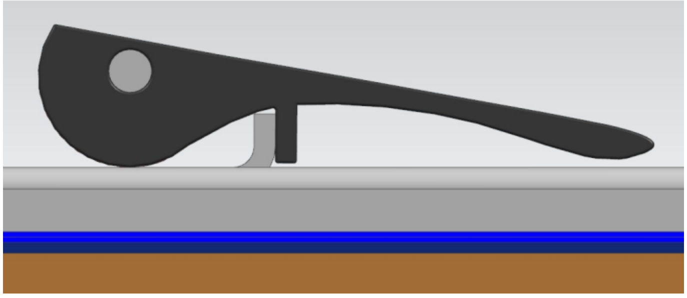
Picture 36: The canvas clamp is slid 34 mm in left direction against the vertical plate.



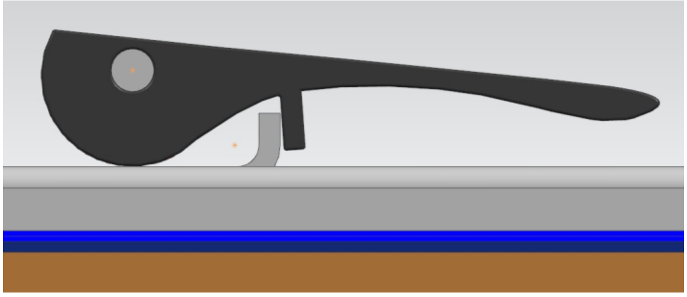
Picture 37: The cam levers are locked and the canvas clamp compresses the canvas ca 2 mm.

LOCKING THE CAM LEVERS

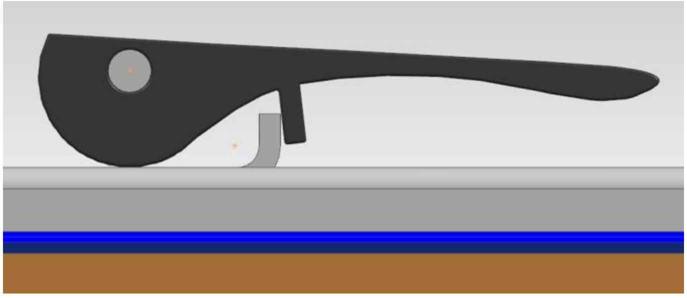
The difference between the fastening wheels and the cam lever locks is that the latter, in addition to push the canvas clamp downwards, also pushes it in horizontal direction against the vertical plate. As described in Picture 36, the canvas clamp is slid 34 mm by hand. When the cam lever locks, another 2 mm of horizontal push is applied. This is visualised in Picture 38 – 42 where the incremental change horizontal direction for the canvas clamp is 0.5 mm.



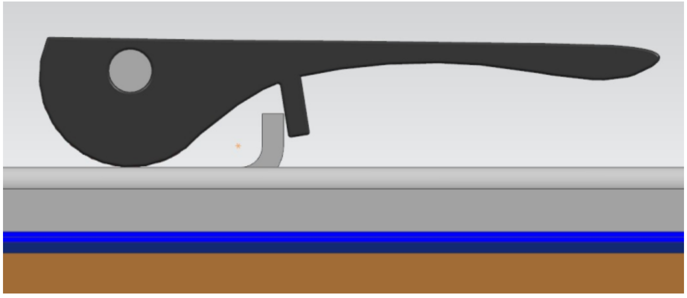
Picture 38: Cam lever in locked position



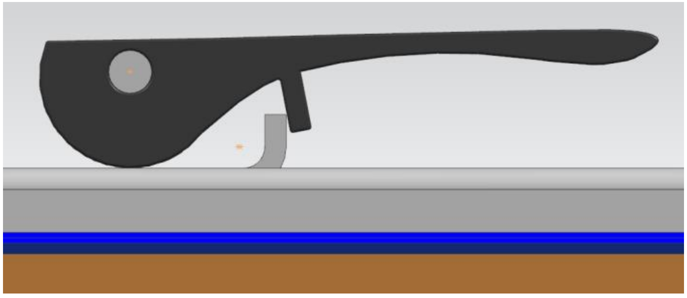
Picture 39



Picture 40



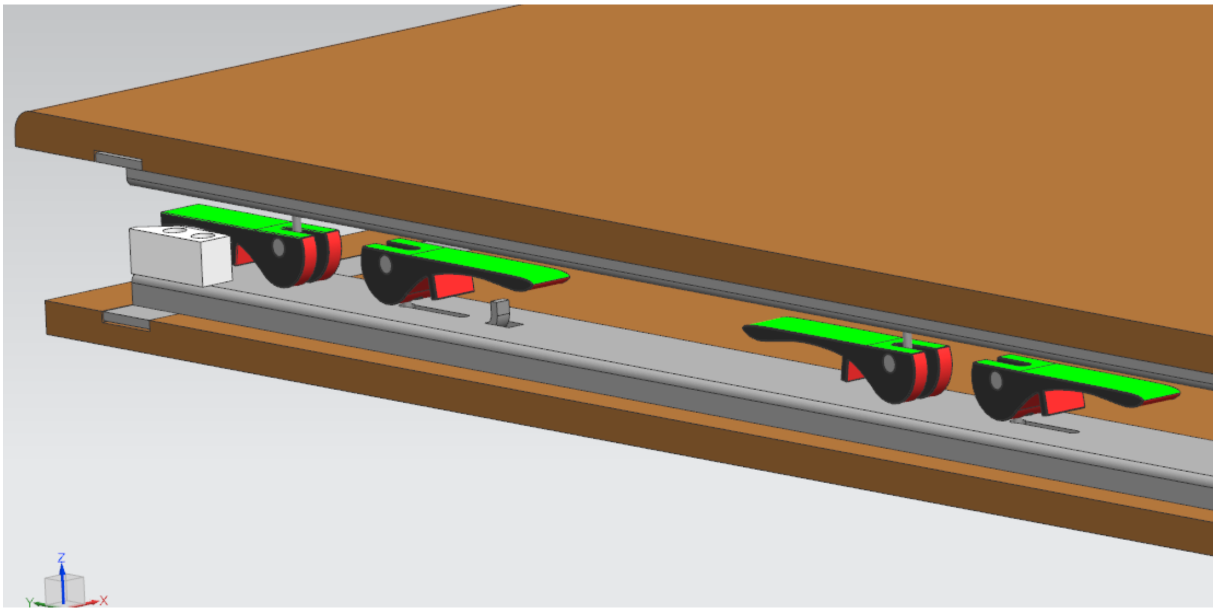
Picture 41



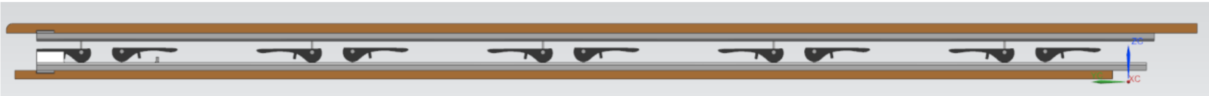
Picture 42

FOLDING THE PANEL

The panel folds together in the same way as is the current panel. The cam levers on the horizontal plate is stored in locked position while the cam lever on the vertical plate are stored in open position (Picture 43). This to avoid conflict when folding the panel together.



Picture 43: Folded position. Canvas is removed for better visualisation.



Picture 44: Side view of folded position. Canvas is removed for better visualisation.

4.3.2 Adjustments needed on current panels

The new suggested solution is not far from the original concept, and will therefor require less effort for AquaFence to implement. Table 25 shows which parts in the current concept that need to be removed and which parts that need to be replaced with new parts.

Parts in current system	**Replaced by:**
Fastening wheels (part #10038) with Unbrako ISO 7380 M8X60 bolts (part #10013) and M8 DIN 6798 toothed washer (part #10013)	Cam lever lock (including the lever, pin and bolt) and M5 grip nuts.
Canvas lock sheet (part #10043)	New Lock sheet
Horizontal and vertical canvas clamps.	New Canvas clamps
Latitudinal eccentric lock (part #1004) with ISO 10642 M6x8 screws (part #10262).	Removed
Canvas clamp hook with (part #10123) with Unbrako ISO 7280 M8x25 screws (part #10008) and M8 Grip nut (part #10033)	Removed

Table 25: Replacement parts

4.3.3 Components

The new or modified components are described in this section.

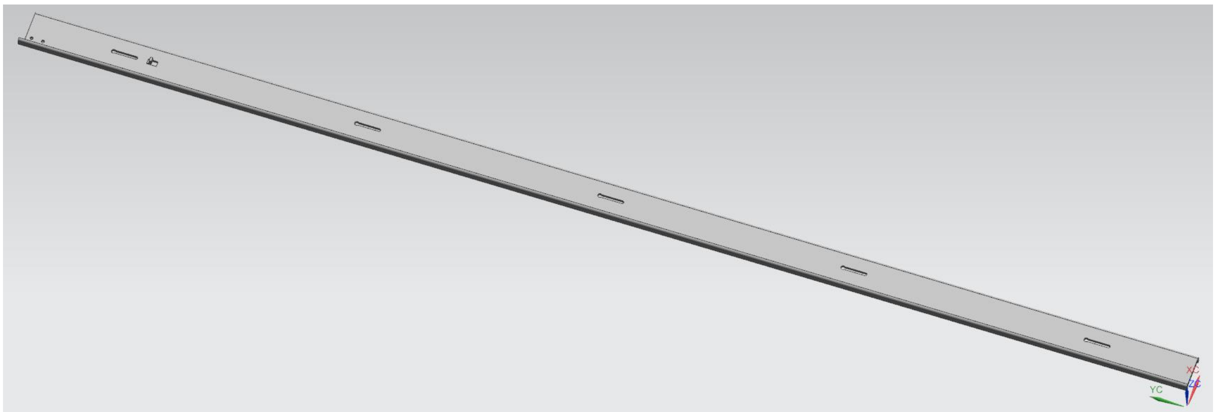
HORIZONTAL CANVAS CLAMP

The horizontal canvas clamp is more or less equal to the current canvas clamp. The profile (Picture 45) has the same height, width and material thickness.

Picture 45: Profile of canvas clamp

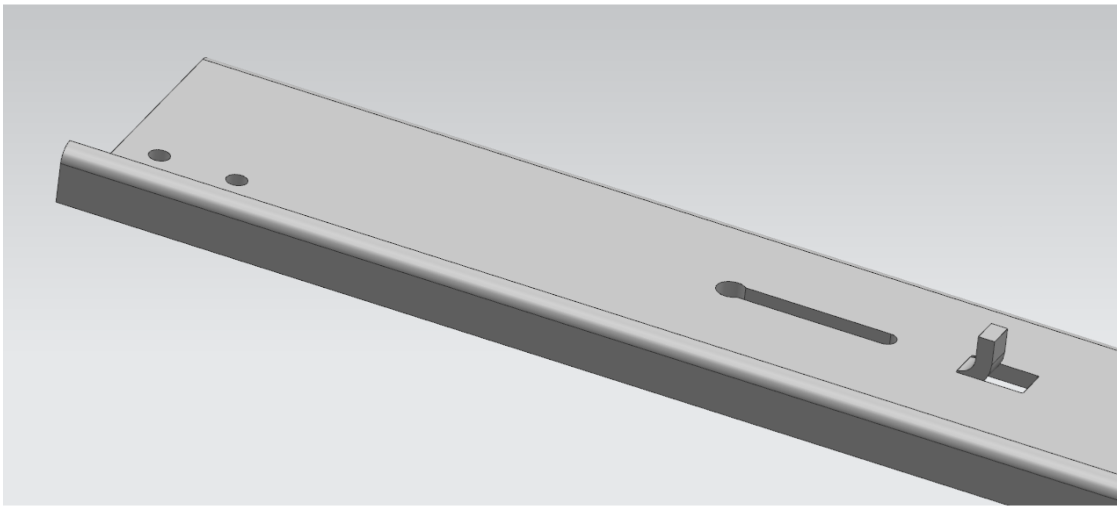
The length of the clamp is extended from 1950 mm to 1971 mm. This is because the canvas lock sheet is placed on top of the canvas clamp, and not as an extension of it.

The canvas clamp has five holes or grooves for the cam lever locks (Picture 46). Five grooves, which is the same number of fastening wheels, are chosen to make it easier to implement the new system on the current panels. A version with fewer cam lever locks could be tried, but then the grooves would need to be placed otherwise. The width of the grooves is reduced compared the current grooves and they allow a latitudinal movement of 36 mm. 36 mm is less than the current possible movement, and this is because the canvas clamp only is drawn back what is necessary when stored. The current canvas clamp is drawn back more than necessary.



Picture 46: Horizontal canvas clamp

Picture 47 shows the end of the canvas clamp that pushes the canvas into the vertical plate. Compared to the current canvas clamp, this one has a rectangular piece cut away. This is done to decrease the area that is in contact with the canvas in order to increase the pressure at the contacting surface. The two holes are for attaching the canvas lock sheet.



Picture 47: The end of the canvas clamp

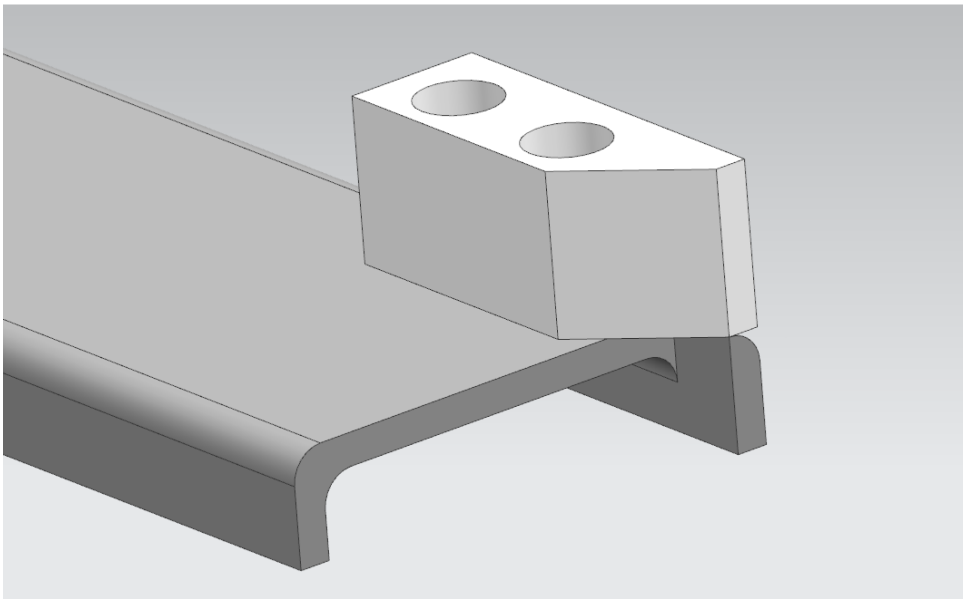
The same picture shows also a little tap pointing out form the canvas clamp. This tap is where the cam lever applies the horizontal force, and it keeps the canvas clamp in the correct position. There is only one of these taps on the canvas clamp. Instead of having the tap bent out from the canvas clamp, a simple block could be bolted to the canvas clamp and serve the same function.

Additionally, the holes for the latitudinal eccentric lock are removed

CANVAS LOCK SHEET

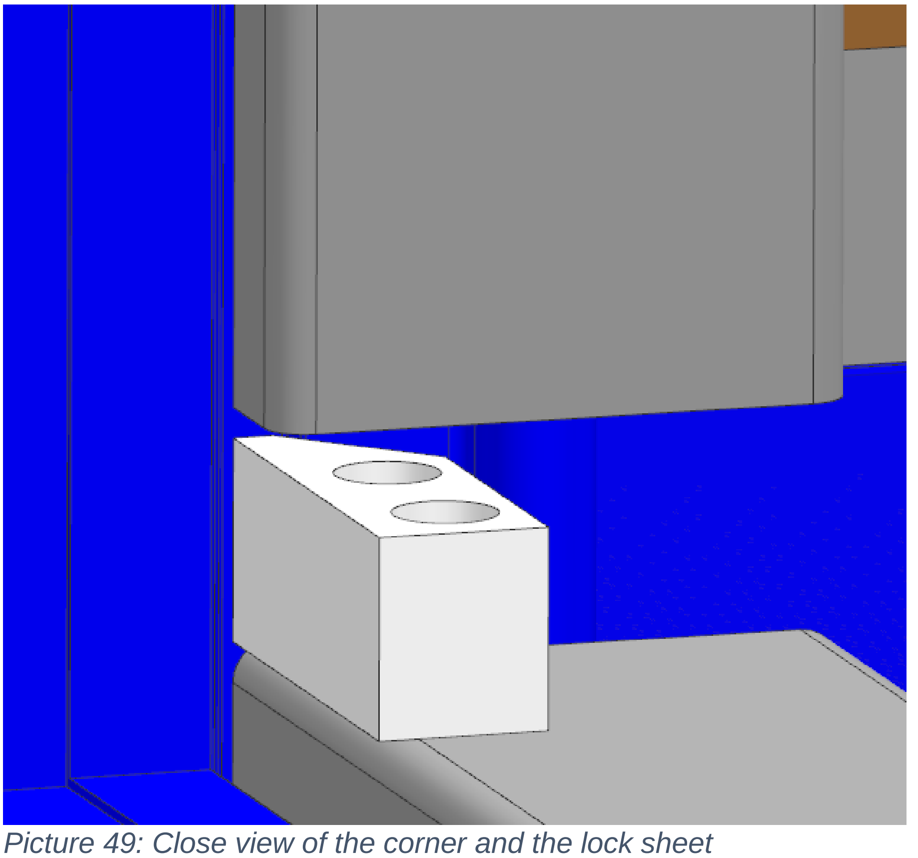
The new lock sheet has a simplified geometry, but use the same bolts and holes as today (Unbrako ISO 7380 M6x20, part #10005 x2). The lock sheet has no longer any fragile parts or excessive material.

The contact face that pushes on the canvas is reduced in order to increase the pressure at the contacting surface. Picture ##54 shows how the lock sheet is flush with the canvas clamp and is a continuation of the projected tap so that the pressure is applied correctly on the vertical canvas. The lock sheet also function as a protection for the projecting tap.



Picture 48: The new canvas clamp

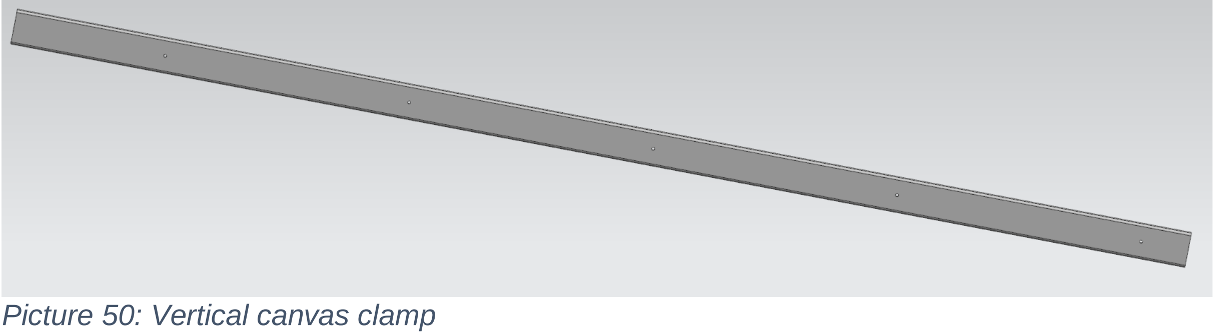
When the system is in use (Picture 49), there is a clearance of 2 mm between the lock sheet and the vertical canvas clamp.



Picture 49: Close view of the corner and the lock sheet

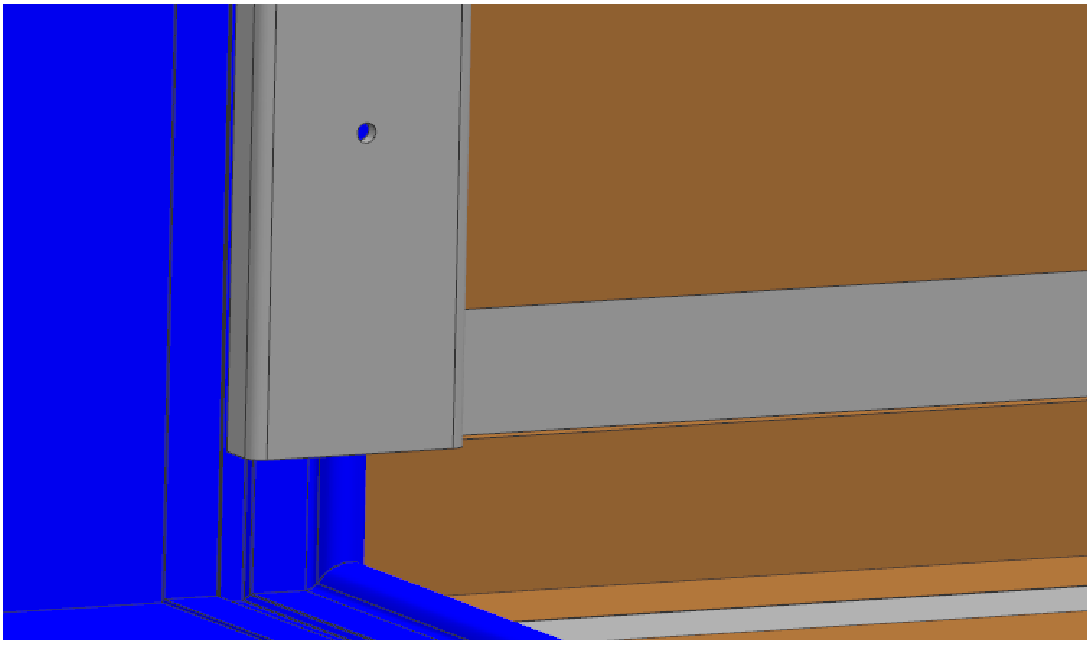
VERTICAL CANVAS CLAMP

The vertical canvas clamp (Picture 50) is also more or less equal to the current vertical canvas clamp. The profile has the same height, width and material thickness and the length is also alike.



Picture 50: Vertical canvas clamp

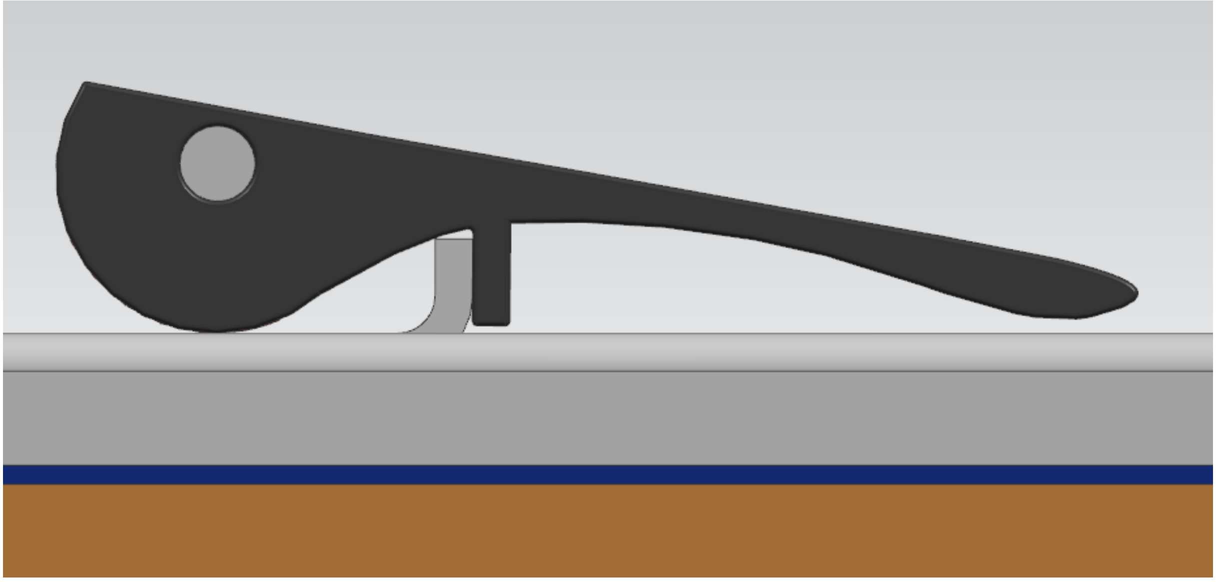
The big difference is that the new vertical canvas clamp has holes instead of grooves for the cam lever locks (Picture 51). The vertical canvas clamp does not need any vertical adjustment and the possibility for this is therefore removed.


Picture 51: Holes in the new vertical canvas clamp

CAM LEVER LOCKS

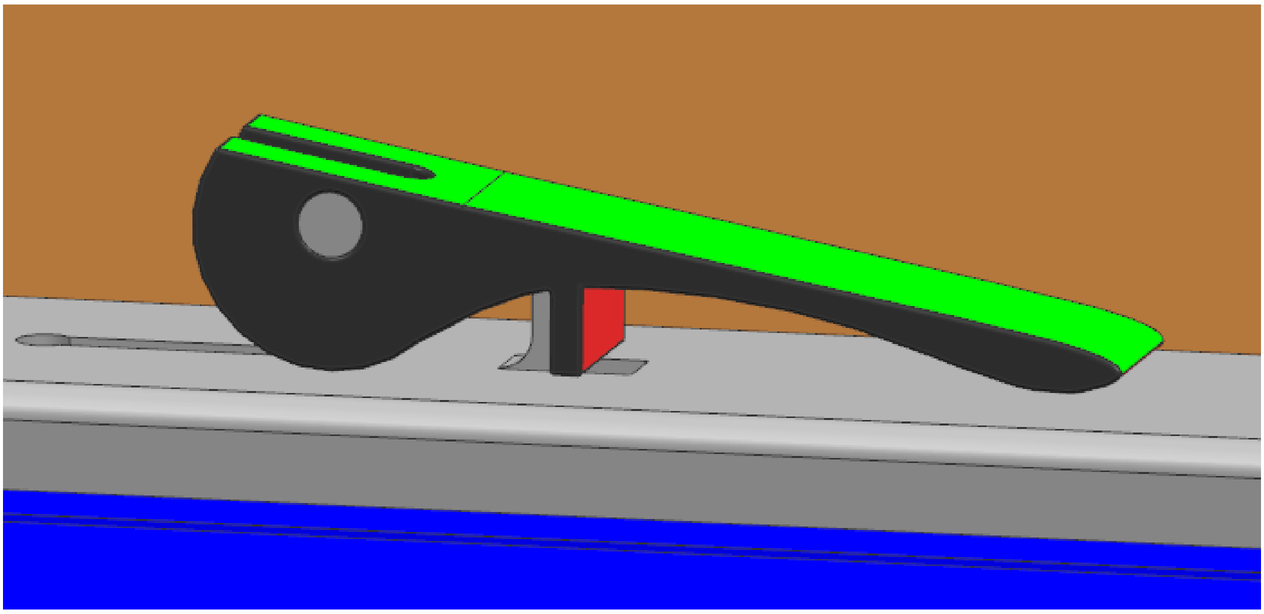
The replacement of the fastening wheels is one of the leading changes in the new system. The cam levers are the locking mechanism for the system and are placed at the same positions as the fastening wheels.

The cam lever (Picture 52) is custom designed because there are several distance wise constraints in the system, especially regarding how tall the locking mechanism can be when the panel is folded. The radius of the curve of the lever is 17 mm, and the centre is 1 mm off the pivot point. The lever has its maximum push force when it is levelled. At picture (Picture 52), it is 10° over levelled position and locks also the canvas clamp in horizontal direction. The geometry in the CAD-models is based on the condition that the cam lever locks and the canvas clamps compress the canvas from 4 mm thickness to 2 mm.


Picture 52: The cam lever lock

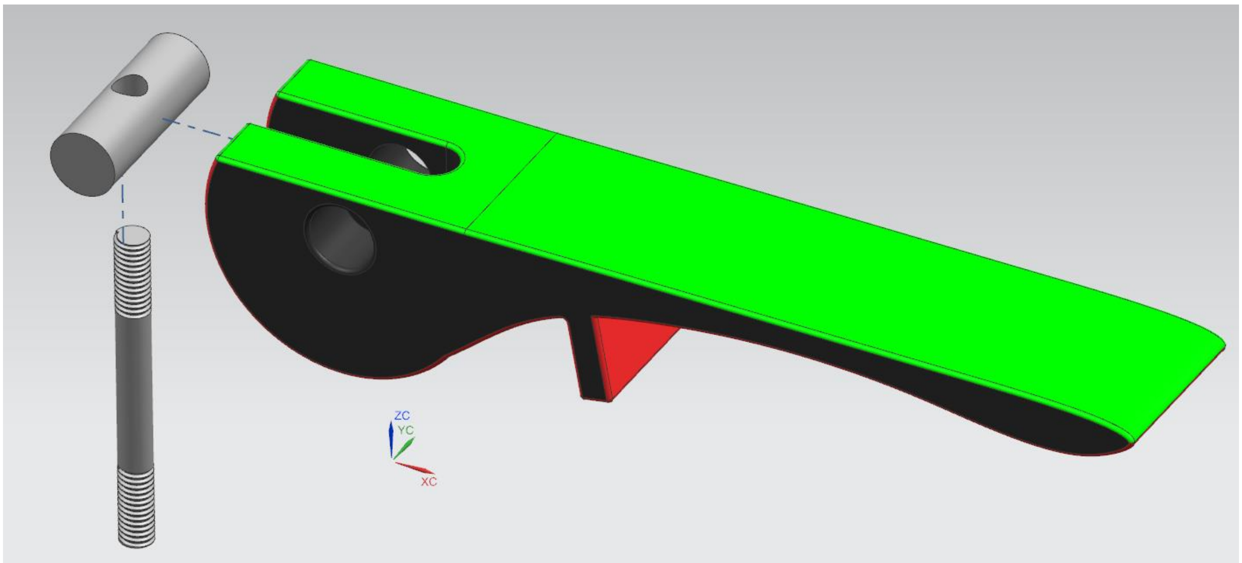
All the cam levers have the stopping pin, in spite the fact that it is only in use by one of them, namely the one on the horizontal canvas clamp closest to the vertical plate. This is done to avoid confusion when assembling. Having fewer different parts is also more economically.

To make it easier to check whether the system is correctly installed or not, even from a distance, the cam levers are colour coded (Picture 53). They are green on top which means that the system is installed safe and properly. The underside is red, giving a warning that action is needed in order for the system to be safe.



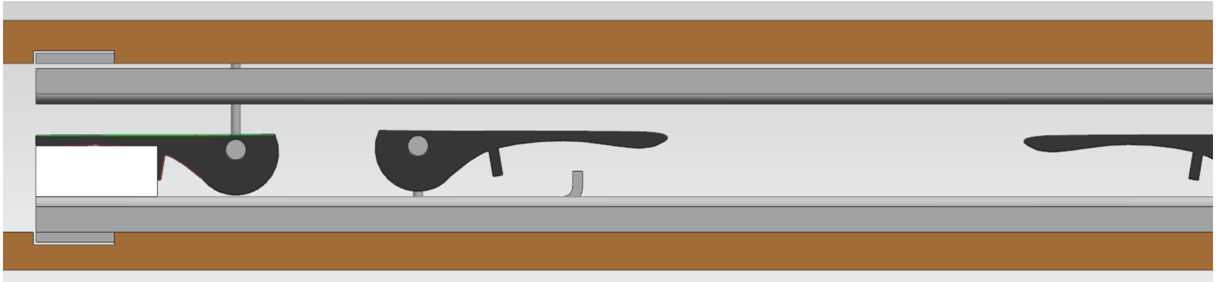
Picture 53: The cam lever is green on top and red underneath

Picture 54 shows the different parts of the cam lever lock. The pin is placed inside the lever and screwed onto the dual threaded bolt which in turn is screwed into a M5 grip nut in the plate.



Picture 54: Different parts of the cam lever lock

The cam lever is 115 mm long and provides a good grip for a normal hand. This applies for all the levers except the lowest one on the vertical canvas clamp. That lever is cut by 20 mm to not come in conflict with the canvas when the panel is folded (Picture 55). This could be solved by moving the cam lever lock 20 mm higher up.



Picture 55: Side view of the folded panel

One aspect that is not optimal with the new system is the fact that the cam levers on the vertical plate needs to be in open position when stored to not come in conflict with the horizontal cam levers (Picture 55). This is an issue because the cam lever will then show the red colour when the panels are folded, even though no action is needed.

The cam levers on the vertical plate could instead have been assembled in a way that they point downwards when in locked position, but that would lead to an even bigger issue. When opening the levers to feed the canvas underneath the canvas clamp, the levers would fall down and lock before the canvas was properly fed.

Another option to solve this issue could be to rearrange the positions of the cam lever locks. This would allow both the horizontal and the vertical cam levers to be stored in locked position, but would also require changes in both canvas clamps and plates.

4.3.4 Selected solutions

The selected solutions for different functions are shown in the morphological box in Figure 12. Functions are shown to the left and some possible solutions for those functions are shown to the right. The selected solutions are marked with orange boxes.

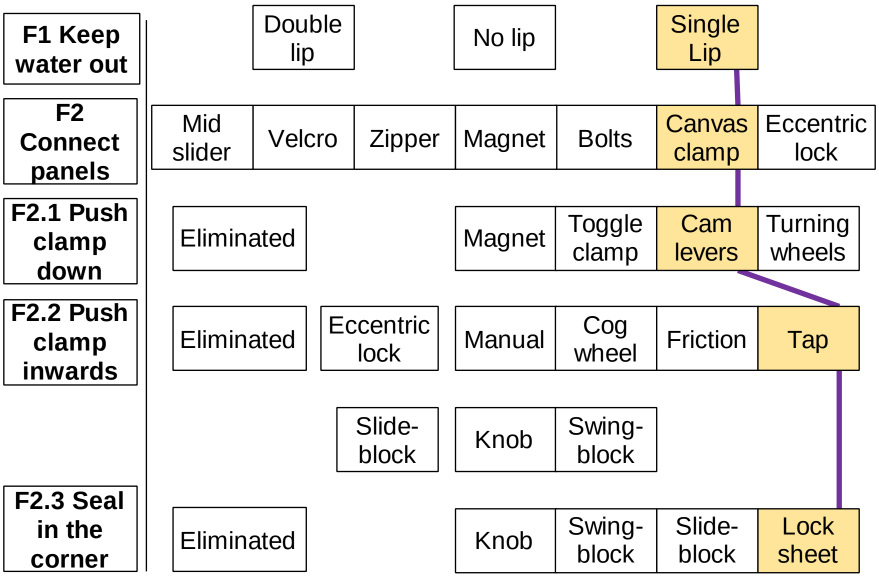


Figure 12: Morphological box with the selected solution

4.4 Verification and validation

Verification is a confirmation that the system meets the previous identified specifications while validation is a confirmation of whether the system works in its intended way (Halpin 2003). Verification and validation is important because of their direct influence on production performance and eventually influence on product functionality and customer perception (Maropoulos and Ceglarek 2010). The new system was presented in the previous section, but it is still unknown whether the system is working as intended or if it meets the identified specifications.

A validation is usually performed only after a verification (Blanchard 2011), but since several of the specifications are based on the results from the validation test, the validation test is described first. Thereupon comes a verification of demands and requirements followed by the systems compliance with current problems. Applied guidelines from DfX is included to confirm that the system is designed in a holistic perspective. The validation ends by describing the system's compatibility with other product variations, and an assessment from AquaFence' point of view.

4.4.1 Testing the new system

To validate the designed system, a prototype was built at AquaFence' production site in Latvia. In order to compare the new system with today's system, the same test procedure that was described in Section 2.7, and used in Section 3.7 on the current system, is also used here for testing the new system. This will among others measure task time, task success, errors and satisfaction. As described in Section 2.7, it consists of both a recorded time study and a SUS questionnaire.

Elements that are not presented in the test procedure earlier, but are special for this particular test are the following:

- Three tests has been carried out.
- The test was done with V1200 panels, but the results are extrapolated to represent V2100 panels.

The installation procedure with all its activity steps are described in both Table 26 and Table 27.

TASK SUCCESS

	Task description		Task success						
			Current system			New system			
	Current system	New system	#1	#2	#3	#1	#2	#3	avg.
1	Loosen the fastening wheels/cam levers on the horizontal and vertical canvas clamps.		1	1	1	1	1	1	
2	Slide the PVC canvas under the horizontal and vertical clamps.		0.5	0.5	0.5	0.5	0.5	0.5	
3	Pull up the vertical canvas clamp		0	1	1				
4	Slide the horizontal canvas clamp against the vertical panel.		0	0.5	1	1	1	1	
5	Hand tighten the fastening wheels on the horizontal clamp.	Fasten the first cam lever on the horizontal clamp.	1	1	1	1	1	1	
6		Fasten the rest of the cam levers on the horizontal clamp.				1	1	1	
7	Fasten the latitudinal eccentric lock on the horizontal clamp.		1	1	1				
8	Re-tighten the fastening wheels on the horizontal clamp.		1	1	1				
9	Push the vertical clamp down firmly against the horizontal clamp.		1	1	1				
10	Tighten the fastening wheels/cam levers on the vertical canvas clamp		1	1	0.5	1	1	1	
11	Check that the eccentric lock on the horizontal clamp is secured.		1	1	1				
12	Check that all the fastening wheels are tight		1	1	1	1	1	1	
13	Loosen the fastening wheels/cam levers on the horizontal and vertical canvas clamp.		1	1	1	1	1	1	
14	Slide the PVC canvas out from the horizontal and vertical clamps.		1	1	1	1	1	1	
15	Pull back the horizontal canvas clamp		1	1	1	1	1	1	
16	Lift the vertical canvas clamp		1	1	1				
17	Fasten the fastening wheels/cam levers on the horizontal and vertical canvas clamp.		1	1	1	1	1	1	

Table 26: Installation steps and task success for current and new system.

	Avg.	#1	#2	#3	#1	#2	#3	Avg.
Number of steps		16	16	16	11	11	11	
Steps completed	15.3	14	16	16	11	11	11	11.0
Task success	96 %	88 %	100 %	100 %	100 %	100 %	100 %	100 %
Number of errors	2.3	3	2	2	1	1	1	1
Number of errors that was fixed	1.7	1	2	2	1	1	1	1

Table 26 continues.

The full table and calculations can be found in Appendix 8.5.

The results from Table 26 will be discussed in more depth in Chapter 5, but the table shows clearly that the step of sliding the canvas underneath the canvas clamp is a source of error in all the tests carried out.

TASK TIME

	Task description		Task time							
			Current system				New system			
	Current system	New system	Avg.	#1	#2	#3	#1	#2	#3	avg.
1	Loosen the fastening wheels/cam levers on the horizontal and vertical canvas clamps.		87.5	103	72	43	12	12	12	11.7
2	Slide the PVC canvas under the horizontal and vertical clamps.		47.3	45	38	59	60	65	50	58.3
3	Pull up the vertical canvas clamp		2.0	2	3	1				
4	Slide the horizontal canvas clamp against the vertical panel.		2.0	2	2	2	5	5	4	4.7
5	Hand tighten the fastening wheels on the horizontal clamp.	Fasten the first cam lever on the horizontal clamp.	56.7	45	68	17	3	3	3	2.8
6		Fasten the rest of the cam levers on the horizontal clamp.					6	6	6	6.0
7	Fasten the latitudinal eccentric lock on the horizontal clamp.		7.0	10	7	4				
8	Re-tighten the fastening wheels on the horizontal clamp.		29.2	42	17	13				
9	Push the vertical clamp down firmly against the horizontal clamp.		2.0	1	2	3				
10	Tighten the fastening wheels/cam levers on the vertical canvas clamp		68.3	70	67	50	17	13	12	13.9
11	Check that the eccentric lock on the horizontal clamp is secured.		1.0	1	1	1				
12	Check that all the fastening wheels are tight		5.3	7	5	4	1	1	1	1.0
13	Loosen the fastening wheels/cam levers on the horizontal and vertical canvas clamp.		110.0	117	103	40	13	12	10	11.4
14	Slide the PVC canvas out from the horizontal and vertical clamps.		7.8	10	5	8	8	5	5	6.1
15	Pull back the horizontal canvas clamp		1.0	1	1	1	1	1	1	1.0
16	Lift the vertical canvas clamp		1.0	1	1	1				
17	Fasten the fastening wheels/cam levers on the horizontal and vertical canvas clamp.		82.5	80	85	40	9	8	9	8.9

Table 27: Installation steps and task time for current and new system

	Avg.	#1	#2	#3	#1	#2	#3	Avg.
Time used to correct errors	10.0	3	3	24	3	6	3	4.0
Total time [seconds]	507	536	477	287	134	131	113	126
Total time [min]	8.4	8.9	8.0	4.8	2.2	2.2	1.9	2.1
Time, % of the best		21 %	24 %	39 %	84 %	86 %	100 %	

Table 27 continues.

The full table and calculations can be found in in Appendix 8.5.

Table 27 shows clearly that it takes around 2.1 minutes to install the new system. It also shows that sliding the canvas underneath the canvas clamps takes the most time and stands for 46 % of total time used. It also shows that there is an improvement in several metrics.

SUS SCORE

The scores from the SUS questionnaire from the installation are provided in Table 28. Question 1 was left out and scored neutrally (3) since the question is of very little relevance for the system tested.

		Question #											
		1	2	3	4	5	6	7	8	9	10	SUS Score	Average
Test #	1	3	4	2	2	2	3	2	5	1	5	27.5	35.0
	2	3	4	3	1	2	3	3	5	2	3	42.5	
	3	3	4	3	2	2	3	3	5	1	4	35.0	
	4	3	2	4	1	4	2	5	2	4	1	80.0	87.5
	5	3	1	5	1	5	1	5	1	5	1	95.0	
	6	3	2	5	1	5	2	5	2	5	1	87.5	

Table 28: Results from current and new system from the System Usability Scale

The table shows that the new system (test 4, 5 and 6) has a significant higher SUS score than the current system (test 1, 2 and 3).

WEIGHT

The measured weight from the new and the current system is provided in Table 29 below.

Current system	**New system**	**Current [g]**	**New [g]**	**Change**
Canvas		1302	1302	-
Vertical canvas clamp		1528	1528	-
Fastening wheels and bolts. 10 á 72g	Cam levers and bolts. 10 á 63g	720	630	-13 %
Horizontal canvas clamp		1500	1500	-
Canvas lock sheet		28	10	-64 %
Screws for Canvas lock sheet		10	10	-
Latitudinal eccentric lock with screws	Removed	210		-100 %
Canvas clamp hook with screw	Removed	63		-100 %
Longitudinal eccentric lock with screws		726	726	-
Canvas brackets on vertical plate (664g + 358g)		1022	1022	-
Canvas brackets on horizontal plate (664g + 358g)		1022	1022	-
Bolts for brackets on vertical plate 10 á 11g + 5 á 10g		160	160	-
Bolts for brackets on horizontal plate 9 á 11g + 5 á 14g		169	169	-
Total		8460	8079	-5 %

Table 29: Measured weight for the current and the new system

Table 29 shows significant change in some parts, but the total weight reduction is not so great. Today's system consists of 67 parts distributed on 17 different parts, while the new system has 73 parts distributed on 16 different parts.

4.4.2 Fulfilment of product requirements

In Section 3.9, a set of product requirements was established for the new system. When the finished design now is ready, most of these requirements are met and seen in Table 30. Several of the requirements that was established are related to functions or interfaces that has not been changed. Hence the performance is unchanged and most of these requirements are therefore omitted from the table. Similarly, most of the requirements that have not been tested due to lack of testing possibilities are omitted.

	Current system	**New system**	**Within the set requirements?**
Frequency of part replacement	Some of the parts in the new system are less likely to be damaged and needs therefore rarer replacement.		Not tested
Possible reuses	With lower frequency of part replacement, the number of possible reuses are likely to be higher with the new system.		Not tested
Installation steps	16	11	Yes
Installation time	8.4 minutes	2.1 minutes	Yes
Time used to correct errors	10 seconds	4 seconds	Yes
Adequate distance for visual installation check	0 m	2.5 m	Yes
Task success of the installation steps	96 %	100 %	Yes
Systems properly installed	With fewer and more intuitive installation steps, and with a higher success rate for the installation steps, it is likely that more of the new systems are properly installed.		Not tested
Availability	Due to lower frequency of part replacement and more systems properly installed, availability is likely to be higher in the new system.		Not tested
Weight	8460 g	8079 g	No
Height (when folded)	66.5 mm	66 mm	Yes
Highest interaction point above the horizontal plate	1779 mm	1829 mm	Yes
Number of loose parts	0	0	Yes
Number of times persons need to do an installation under surveillance before they can do it unassisted.	The new system has fewer and more intuitive installation steps, and the learnability is therefore likely to have increased.		Not tested

Table 30: Fulfilment of product requirements

4.4.3 Compliance with current problems in the new system

Section 3.6 described different problems and issues with today's system. The system has now gone through a redesign where a lot of these issues have been addressed. Table 31 shows which issues that have been addressed and not, and how it is solved.

Problems or issues	**Fixed?**	**How?**
DURING INSTALLATION		
The fastening wheels		
Time consuming	Yes	Fastening wheels are replaced by one-movement cam levers.
Need of special installation tools	Yes	The cam levers do not require installation tools.
The possibility to overtighten/ apply too much force	Yes	The cam levers cannot be overtightened by the installer.
Access to the uppermost fastening wheel	No	This issues has not been addressed.
The wires tend to snag in/around the fastening wheels	No	The wires can now snag around the cam levers instead of the fastening wheels.
Scratching knuckles	Yes	The turning movement is eliminated and the surface of the canvas clamp is now smooth without grooves.
Difficult to know when a wheel is turned enough.	Yes	The wheels are replaced by cam levers that are either open or closed.
Difficult to remember to inspect the wheels.	Yes	The wheels are replaced by colour coded cam levers that immediately and unsolicited shows whether the lever is open or closed.
The canvas clamp		
It cannot be adjusted easily	Yes	The need for adjustment at the vertical canvas clamp is eliminated. The canvas clamp is more easily adjusted since it can be adjuster faster.
The horizontal clamp must be adjusted before the vertical one.	Yes	The vertical canvas clamp is fixed and no longer adjustable.
Sometimes in conflict with the longitudinal eccentric lock	No	This issues has not been addressed.
It is not intuitive	Yes	Solved by eliminating possibilities for uncertainty for the installer.
The canvas		
It jumps out during installation	No	This issued was revealed late in the process and has not been addressed.
DURING OPERATION		
Canvas lock sheet		
Does not seal 100 % in the corner.	Partly	The part on the old lock sheet that hindered perfect sealing is eliminated, but it is not sure that this will lead to 100 % sealing.
Brakes easily	Yes	The protruding part is eliminated.
Vertical canvas clamp		
A little crevice that arises between the uppermost part of the canvas camp and the plate.	No	This issues has not been addressed.

DURING REMOVAL PHASE		
Time consuming	Yes	Fastening wheels are replaced by one-movement cam levers.
Need of special installation tools	Yes	The cam levers do not require installation tools.
The possibility to overtighten/ apply too much force	Yes	The cam levers cannot be overtightened by the installer.
DURING STORAGE AND TRANSPORTATION		
Thickness of the panel when folded.	No	The thickness of the new system is approximately like the current one.

Table 31: Compliance with current problems in the new system

Table 31 shows that 67.5 % of the issues are solved.

4.4.4 Applied guidelines from Design for X

Design for X was thoroughly described in Section 2.3, and has during the action research been working in the background as guide and running evaluation of design decisions made.

There are numerous design guidelines in DfX that is possible to apply (Huang, 1996), however, DfX approaches focus on a specific phase of product lifecycle or specific aspect of the product. Consequently a holistic optimisation of product design using DfX is highly complex (Dombrowski et al. 2014). To cope with this, it is necessary to determine the effect of different design guidelines on the various lifecycle phases and virtues.

Dombrowski et al. (2014) made an analysis table to point out the qualitative effects of each qualitative design guidelines on several product properties. He sorts the qualitative design guidelines based on their number of mentions in different DfX approaches. In this way, those design guidelines that have the widest effect will top the list.

Table 32 is such a table and shows what design guidelines that have been applied in the new system. It also indicates which life phase or virtues that is improved by applying a given design guideline. Some of the guidelines are already implemented in the current system and are kept in the new system. The list of design guidelines is inspired by Dombrowski's table and supplemented with design guidelines from Section 2.3.

	Design for											
	DfX virtues						DfX life phases					
Qualitative design guidelines applied in the new system	Quality	Cost	Environment	Safety	Maintainability	Reliability	Manufacturability	Assemblability	Transportability	Usability	Recyclability	# of X's affected
Minimize the needs for special tools					X		X	X		X	X	5
Reducing design complexity		X				X	X	X			X	5
Provide simple handling and transportation					X		X	X	X			4
Avoid hazardous and otherwise environmentally harmful materials			X	X						X	X	4
Avoid tiny parts					X	X	X	X				4

Reduce the number of different parts.		X			X			X			X	4
Avoid mechanically rotating parts.				X	X	X		X				4
Design robust components that does not break easily	X		X			X				X		4
Design symmetrical parts or exaggerate asymmetry				X	X			X				3
Minimise the number of design variants							X	X	X			3
Keep the number of parts at a minimum		X						X			X	3
Emphasise quite-running parts	X			X						X		3
Allow easy detection and isolation of failures				X	X	X						3
Use redundancy where possible	X			X		X						3
Avoid parts that are sensitive to acceleration and vibration.	X					X			X			3
Avoid parts that are sensitive to temperature, pressure and humidity.	X					X			X			3
Make the controls and their functions obvious, provide direct feedback from the product						X				X		2
Reduce the number of installation steps					X					X		2
Design the component so that it can be machined with a minimum number of tools and with standard tools.		X					X					2
Favour objects with planes at right angles to each other							X	X				2
Design the component so that it can be machined with a minimum number of tools and with standard tools.		X					X					2
Only use recyclable material			X								X	2
Reduce number of movements in the installation steps/usage.										X		1
Reduce the physical effort needed to use the product										X		1
The dimensional limits should be concerned so that replaceable units can be transported to a repair shop.					X							1
Allow easy access and exchange for all replaceable parts					X							1
Include visual alerts to show if the product is used/installed correctly.						X						1
Inside radii on bends should not be less than the thickness of the metal.							X					1
Avoid the use of undercuts where possible.							X					1
Emphasise that installation/use can be done one-handed										X		1
Avoid the need for simultaneous operations										X		1
Avoid the need for installation/use in a predefined sequence.										X		1
Design ergonomically for the proportions of an average person.										X		1
Sum	**5**	**5**	**3**	**7**	**11**	**10**	**10**	**11**	**5**	**13**	**7**	

Table 32: Qualitative design guidelines applied in the new system. Adapted from Dombrowski et al. (2014).

Table 32 shows how DfX has been used in the new system and what aspects of the system it has had an influence on. Furthermore it demonstrates that design decisions have been evaluated holistically from a range of different perspectives. 68 % of the implemented guidelines have a wide effect by benefitting two or more life phases or virtues.

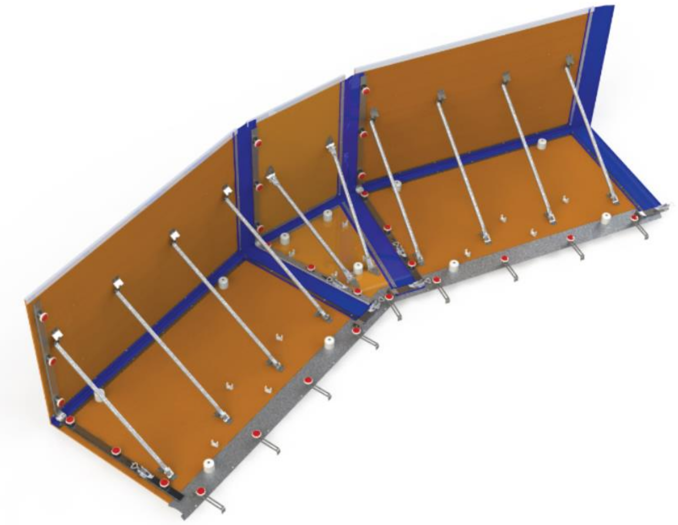
Design for quality, cost, environment and transportability have relatively few design guidelines related to them, but that does not necessarily mean that these DfX approaches are less ensured. The table does not specify the extent of correlation. In reality the correlation will span from very strong to very weak, and even to negative.

4.4.5 Compatibility with other product variations

The development done in the action research here in Chapter 4 has focused on creating a new system for connecting two regular V2100 flood protection panels. However, as described in Section 3.2, the current system is used in different product variations.

The design has not changed drastically, and several aspects from the current design is passed on to the new design. The canvas is identical and so are the holes for holding the fastening wheels/cam levers. The principal structure of the canvas clamp is also the same, even though there are some variation in the placements and size of the holes in it. Therefore the main change from the current to the new system is how the canvas clamps are pushed down onto the canvas. There is no reason that these changes should affect the ability of the new system to be used in other product variations.

When looking at the connection part in the current system, the only difference between V1200, V1800 and V2100 is the size of canvas and canvas clamp, and amount of fasteners. When applying the new developed system on V1200 and V1800, the length of the canvas must be shortened and only 6 and 8 cam levers are needed. The canvas clamps must also be shortened down.



Picture 56: There will be no problem to apply the new system in all the current product variations.

When looking at the other variations like inside and outside corner, side closures, mix of panel height or solution to cover steps, neither of these will cause problems when applying the new system on them. The same argument is valid; the elements of the connection system that interacts with the plates are more or less alike those in the current system

The holes in the plates for connecting the fastening wheels in V2100 are placed otherwise than V1200 and V1800. Because of this, the placement of these holes in V1200 and V1800 needs to be assessed to avoid the cam levers from colliding when the panel is folded.

4.4.6 Preliminary assessment of the new system by AquaFence

AquaFence is very satisfied with the preliminary demonstrations of the new solution, and express that they think the new system, at least parts of it, has a potential. They recognise the improvements of faster and easier installation, and that this increase the user experience. Despite the increase in user experience, it is difficult to justify and increase in selling price based on that. Pricing solely based on a product's performance and appearance, and not on market needs and willingness to pay, is difficult because there are very few equivalent products in the market. It is therefore easier to justify a price increase based on increased production costs rather than increased user experience. If the new system is implemented, the value will increase for the customer without AquaFence necessarily charging more. The customer will receive more for the same price, and this can be beneficial in the long run (Jumburgs 2015).

5 Discussion

This chapter will discuss the work and results from the case study and the action research. The sections from the thesis will be reviewed and uncertainty, unsolved issues and weak and strong sides will be discussed. After a recapitulation of the case study and the action research, a section with additional limitations is provided.

5.1 Discussion

METHODOLOGY AND PRECONDITIONS

The study started by introducing several theories. When looking into literature, one finds numerous of different theories, methodologies, approaches and tools for engineering design and product improvement (Clarkson and Eckert 2005). Unfortunately, there is no design model available which is agreed to provide the ultimate satisfactory description of the design process (Bahrami and Dagli 1993). Some theories and methodologies that appeared to be suitable were chosen, and the outcome, the study and the results, is of course influenced by that choice. A fishing net and a fishing rod result in different catches.

If theories such as concurrent engineering, integrated product development, lean product development had been introduced as well, or as a substitution, the thesis would have had another structure. If the end results and recommendations would be far from the current one is not possible to know for sure.

Value was defined as the ratio of user experience to cost (Eq. 4) and has been a key relation throughout the thesis. The logical reasoning behind this equation can be questioned. User experience has several aspects, including, but not limited to functionality, performance, emotions and perceptions (ISO 9241-210:2010). Park (1998) said that increased functionality lead to increased value, Crow (2002) stated that increased performance and focus on emotions lead to increased value, while Browning (2003) formulated a ratio where the value was increased by increasing the perceived benefits. All these aspects of the user experience lead to increased value, but that does not imply that other aspects of user experience necessarily lead to increased value. It is therefore not entirely correct to say that user experience leads to increased value, but rather that several user experience aspects lead to increased value.

THE CASE STUDY

The case study in Chapter 3 consisted of inputs from several areas and aspects. One can discuss if these inputs are appropriate, if more or other types of inputs should be included, but by structuring the work around the IPM model and the value analysis, the process has been quality assured.

Section 3.3 decomposed the system and defined the system of interest. Such delimitation makes the work load and the project manageable, but to look at the system of interest isolated from rest of the panel might not be the optimal approach. Exclusive focus on one subsystem without simultaneous attention to the parent system and other subsystems leads to suboptimal results and new disturbances (Haines 2006). Due to restricted time and resources, and of course due to the objective in the thesis, this delimitation was necessary. Despite Haines' statement, I believe that even though only the sub system was considered, the user experience of the parent system has increased because the one system of interest is a major part of the parent system. Also, no deterioration has been observed on the parent system.

Another delimitation that was made was to exclude the longitudinal eccentric lock from the scope. The longitudinal eccentric lock is actually a crucial part when two panels are connected. It is definitely a part of the system, and its function is to pull the panels together to seal the underlying foam gasket. To exclude such a vital part might not have been judiciously, though it allowed more focus and effort on the other elements.

The user situation section stated that flood disasters in the period of 2001 - 2010 cost approximately USD 200 billion worldwide, and that the frequency of flood events is steadily increasing (World Meterological Organization 2014). The potential seem to be enormous, but it is important to remember that AquaFence' flood protection system in not suitable for all conditions. Sandy, silty, uneven or sloping ground should be avoided due to risk of erosion and massive water leakage underneath the panels (Bjork 2013). Additionally, not all flood areas around the globe have economy or interest in buying measures for preventing damage. Still, the potential is huge.

After describing the user situation, several issues revealed through various stakeholders were described. To have this overview is beneficial in the concept phase, because search for solution of problems will generate concepts (Grave 2013).The challenge however, is that none of the issues are first-hand experience from real life situations. The issues stem either from second-hand experience from real situations that are communicated further, or first-hand experience from handling the product in the factory. The sources used when revealing these issues are undoubtedly reliable, but the issues and problems could have been understood in another way if the experiences were first-hand, for instance from participating in a full scale installation of a flood barrier. However, the fastening wheels, the canvas clamps and the canvas lock sheet were those parts that seemed to cause the most trouble.

TESTING THE CURRENT PANEL

The tests performed on the system were good in the way that they tested the user experience through both user satisfaction and performance. User satisfaction was measured through the system usability scale, the most used questionnaire for measuring perceptions of usability (Sauro 2011), while performance was measured through efficiency and effectiveness. The metrics used for efficiency and effectiveness were not randomly chosen, but based on Tullis and Albert (2013) table for appropriate metrics in usability studies.

Even though the test design was good, there was some weaknesses in the testing. First of all, the tests were conducted on V1200 panels, but the time measurements were extrapolated so that it could be valid for a V2100. The V2100 has for instance ten fastening wheels while V1200 only has six. The extrapolation factor was adjusted from activity step to activity step, but in most cases the factor was 5/3. This inconsistency makes the results inaccurate, and there are therefore some uncertainty related to the installation times.

Another weakness with the test of the current system was that very few tests were conducted. The system was only tested three times. Test #1 and #2 were performed without installation tools, and test #3 with tools. Because of this, the average installation times for each installation step that included fastening wheels or cam levers were calculated only from test #1 and #2. With this creative calculation of average time, you need a steady hand when comparing times, or else fallacies can easily be made. For instance, the average total installation time is 8.4 minutes and this is an average of test #1 and #2. The total installation time for test 3 which was performed using installation tools was 4.8 minutes. Even with a few tests performed it is likely that the average installation time would have been lower if installation tools had been used in all the tests, but the underlying statement was that such installations aids were not always available in chaotic and stressful situations.

	#1	#2	#3	Avg.
Number of steps	16	16	16	
Steps completed	14	16	16	15.3
Task success	88 %	100 %	100 %	96 %
Number of errors	3	2	2	2.3
Number of errors that was fixed	1	2	2	1.7
Time used to correct errors	3.0	3	24	10.0
Total time [seconds]	536	477	287	507
Total time [minutes]	8.9	8.0	4.8	8.4

Excerpt from Table 14

If we look closer at the results from Table 14, 16 installation steps were undertaken. When having nothing to compare to, this number does not say much. The number of steps completed and task success is more informative. Task success was 96 %, which is quite high, but the average number of errors is 2.3 per installation. On average 1.7 of these errors were fixed, leaving 1 error unfixed in every second installation. This is not desirable, and for those errors that were corrected, an average of 10 seconds was used for the correction.

Table 14 also shows that activity step 13 "*Loosen the fastening wheels/cam levers on the horizontal and vertical canvas clamp*" takes the most time and counts for 22 % of total time used. All the activity steps related to this type of fastening takes a lot of time. The total time usage on these activity steps when installation tools are not used, is 7.2 minutes. This is 86 % of the total installation time of 8.4 minutes. When installation tools are used, the time used on the same activity steps is only 3.4 minutes. The total installation time is 4.8 minutes, so the percentage is still high with 71 %. The fastening wheels are time consuming, regardless of whether installation tools are used or not.

		Question #										
		1	2	3	4	5	6	7	8	9	10	SUS Score
Test #	1	3	4	2	2	2	3	2	5	1	5	27.5
	2	3	4	3	2	2	3	3	5	1	4	35.0
	3	3	4	3	1	2	3	3	5	2	3	42.5

Table 15: Results from the system usability scale

Table 15 shows the system usability scale results and the current system has an average SUS score of 35. The score is a bit higher when installation tools are used, but the scores are still far below the score of 86 which is considered to be an average good system (Sauro 2011). One of the questions where the answers from the tool-free installation test deviated from the test where tools were used, was the question about confidence. It is natural to believe that a person that is able to perform a task quicker, also will feel more confident than one performing it slower. The tool itself may also increase the confidence

FUNCTIONAL ANALYSIS AND SPECIFICATIONS

After the tests of the current system, the case study continued with a functional analysis. The analysis provided an understanding of which functions that were necessary for the system in order to fulfil its purposes. Also a better understanding of how important these functions, elements and sub-functions are, were provided. Not all of the elements and sub-systems contribute to the main purpose, but are rather considered enabling systems for the others sub-systems. Several parts, even those at the lower levels in the system hierarchy demonstrated a total importance above 90 %. This shows that even small and apparently less important parts may have a fundamental role. Further, this underline the importance of systematically decomposing the functions in order to analyse the components.

Even though the functional analysis was a great contribution in understanding the system, there were weaknesses. The percentage points for the components' relative importance were based on subjective assumption without having any evidences. Still, without considering the importance of each element, the functional analysis was useful in understanding the composition of the system and the functions of the elements. The activities of fastening, sealing and waterproofing were the most prominent functions in the system.

The case study ended with lists of user demands and product requirements. These specifications were deeply rooted in actual needs and demands based on stakeholders' expressions, user situations and a functional analysis. The specifications were also confirmed by AquaFence, but there is no guarantee that the lists are exhaustive. Other specifications that should have been included can exist. A possible reason for this is that information might have been retained in dialogues with stakeholders, because the stakeholders thought the information was not of interest.

Even though there are some weaknesses and uncertainty with the methods and elements in the case study, the study has provided valuable in-depth knowledge about the current system, pointing at areas in the system that should be especially considered when developing a new system.

DEVELOPING A NEW PRODUCT

The background for developing a new system was that AquaFence needed to improve their product in order to keep their market position in the coming years.

The concept development that started in Section 4.1 was grounded on all the input from the case study, combined with guidelines from DfX. That provided an excellent basis for developing an improved system.

In this development phase that the creativity was put to the test. Creativity is essential for design success (Chiu and Salustri 2010), and no matter how many development methods or tools that are used, if creativity is missing, success is further away. A lot of creative solutions did indeed come up in this phase, but when the process was completed by one single person, some solutions must have been missed.

30 more or less suitable solutions was brought up in the concept generation phase. That is a good number, but the differences were mainly in how the canvas could connect to the panel or to another canvas part. Except from those concepts connecting the panels directly to each other, no solution presented an alternative to the canvas. The functional analysis demonstrated that the canvas was an important part, so more effort should have been put into finding alternatives for the canvas.

EVALUATING THE DESIGN

To find the solution with greatest potential, a multiple attribute evaluation was conducted. The evaluation criteria were how well the 30 concepts fulfilled, or had potential to fulfil, the guidelines for the 11 different DfX aspects. The DfX aspects were weighted based on their relative importance. I have not seen DfX aspects used so explicitly in the evaluation in any other engineering design project, but given that it works, the new concept will definitely be evaluated in a holistic DfX manner. Paramasivam and Senthil (2009) has suggested how DfX can be used in analysis and evaluation of product design using a digraph and matrix approach, which is similar to what I have done. This seems however to be a seldom used approach and was reviewed in literature for the first time in 2012 (Baykasoglu 2014).

The evaluation's holistic perspective is promising, but the weighting between the various DfX aspects has some weak points. The weight was assigned using a pairwise comparison, as shown in Table 22.

	Quality	Cost	Environment	Safety	Maintainability	Reliability	Manufacturability	Assemblability	Transportability	Usability	Recyclability	Sum	Normalised sum
Quality	-	2	2	1	2	1	2	2	2	1	2	17	15
Cost	0	-	2	0	2	0	2	2	2	0	2	12	11
Environment	0	0	-	0	0	0	0	0	0	0	2	2	2
Safety	1	2	2	-	2	1	2	2	2	2	2	18	16
Maintainability	0	0	2	0	-	0	1	1	1	0	2	7	6
Reliability	1	2	2	1	2	-	2	2	2	2	2	18	16
Manufacturability	0	0	2	0	1	0	-	2	1	0	2	8	7
Assemblability	0	0	2	0	1	0	0	-	1	0	2	6	5
Transportability	0	0	2	0	1	0	1	1	-	0	1	6	5
Usability	1	2	2	0	0	0	2	2	2	-	2	13	12
Recyclability	0	0	0	0	2	0	0	0	1	0	-	3	3
Sum												110	100

Table 22: Weighting table for different DfX criteria

The different DfX aspects imply a lot, and as described in the theory Section 2.4, the aspects are interconnected and influence each other. It is therefore in many cases problematic to say that one aspect is more important than another. For instance, the weighting table indicates that maintainability is less important than reliability. It is not surprising that reliability is considered more important than maintainability for a flood protection system, but Figure 1 said that maintainability leads to enhanced user experience, safety and reliability. Would it not then be natural to think of maintainability as more important than reliability? Since it leads to reliability in addition to providing its own benefits.

If we look at another example, the table says that usability is equally important as quality. Despite this, quality gets a weight of 15 while usability only obtains 12. The table is therefore inconsistent and should be used with caution. This paradox arise because evaluation attributes are only looked at pairwise, and not as a web of aspects contributing to a shared goal.

With small changes in the weighting table, the results could have had another outcome. If we look back at the evaluation matrix in Table 24, we see that concept X, which is among top two, relegate to the top five if no weight is used at all. It is still likely that concept X would have been chosen for further elaboration since this was a solution that appeared to be easy for AquaFence to implement.

Another issue with the evaluation was that the concepts at that point in time were only concepts. It is hard to assign appropriate scores without knowing the details of the concept. The scores were therefore in many cases assigned based on the potential for good design. To cope with this issue, an uncertainty score was assigned to each suggested concept in the evaluation matrix.

THE NEW DESIGN

When a concept was chosen, the action research continued with a presentation of the new design. The description does not correspond fully with the actually built system. However, there is no reason that the test results should be very different if the built prototype was identical with the CAD-models, at least the results should not be worse. Theoretically, if the prototype was built exactly to the models, it is likely that the test results would have been better.

The suggested design has several benefits, but also some weaknesses. The cam levers lock very easily, but can unfortunately open relatively easy as well. If a stick or some other debris in the flood water is stuck under the lever, it can work as a crowbar and open the cam lever. This should be looked further into if the suggested solution is implemented.

VERIFICATION AND VALIDATION

After the chosen concept was described, the interesting part of verification and validation followed. In order to be able to compare the current system with the new system, the same test procedure was used. This implies that the same weaknesses in the procedure were present. Few tests were conducted and the time is inaccurate due to inconsistent extrapolation.

	Current system				New system				
	#1	#2	#3	Avg.	#1	#2	#3	Avg.	change
Number of steps	16	16	16		11	11	11		-31 %
Steps completed	14	16	16	15.3	11	11	11	11.0	-28 %
Task success	88 %	100 %	100 %	96 %	100 %	100 %	100 %	100 %	4 %
Number of errors	3	2	2	2.3	1	1	1	1	-57 %
Number of errors that was fixed	1	2	2	1.7	1	1	1	1	
Time used to correct errors	3.0	3	24	10.0	3	6	3	4	-60 %
Total time [seconds]	536	477	287	507	134	131	113	125.8	-75 %
Total time [min]	8.9	8.0	4.8	8.4	2.24	2.18	1.88	2.10	-75 %
Time, % of the best	21 %	24 %	39 %		84 %	86 %	100 %		

Excerpt from Table 27.

When looking at the results from the test of the new system and comparing them with the results from the current system, several changes are present. Regarding effectiveness, there has been an increase of 4 % in task success (to 100 %). The reduction in number of errors is of 57 % (to only 1 error). Both the current and the new system have errors in activity step 2, *"sliding the canvas underneath the canvas clamps"*. This error is caused by the canvas that jumps out, and time is needed to put it back in place. An area where only the current system has errors is activity step 4, "*sliding the horizontal canvas clamp against the vertical panel"*. The reason why this error has been eliminated could be explained by the new system having a strong relation and dependency between that activity step and the next one. In order to complete step 5 in the new system, step 4 must first be completed. This dependency is not present in the current system, and the procedure does therefore look less logical there. It is likely to think that the reduction in errors and increase in task success is due to the reduced number of installations steps, making it easier to remember the procedure.

Regarding efficiency, there has also been a reduction in time used at correcting errors. The reduction is of 60 % to 4 seconds. When testing the current panels, it was test #3 that counted for most of the time used to correct errors. This was because the socket adaptor fell of the impact wrench and needed to be replaced. This means that it was not the current system per se that caused this time usage, but the installation tool. If we instead of comparing the current with the new system, compare installation with and without installation tools, the reduction when not using tools is 85 %, from 24.0 to 3.6 seconds.

Table 27 shows also a reduction of 31 % in the number of installation steps required (to 11 steps). A major driver for this decrease is the removal of the latitudinal eccentric lock. The new cam levers serve both the function of pushing downwards and inwards, making the eccentric lock obsolete. It was also an important move to terminate the vertical canvas clamp's possibility to be adjusted vertically.

The reduction in total installation time is 75 %, from 8.4 to 2.1 minutes. The reduction in time usage is likely to come from the replacement of the fastening wheels since the time used on handling the fastening wheels or the corresponding cam levers is reduced from 434 seconds to 55 seconds. Instead of using 86 % of the installation time handling these, now only 43 % of the time is used. When the time consuming activity steps of handling the fastening wheels are eliminated, the activity step that takes the most time is "s*liding the PVC canvas underneath the horizontal and vertical clamps*". This activity takes 53 seconds regardless of system version and should be addressed further in the future. It stands for 46 % of the total installation time in the new system.

The new system was also tested through the system usability scale and the results presented an interesting improvement, going from an average SUS score of 35 to an average of 87.5, an increase of 150%. A drastic difference occurred in almost all the answers in the questionnaire. The question that on the other hand stood out with very little difference, was question 4 *"I think that I would need the support of a technical person to be able to use this system*". Both the current and the new system provide answers with strongly disagree or disagree. It is difficult to point at one specific improvement that has led to the increase in usability, but the reduction in installation time, less installation steps and fewer adjustable parts could be possible answers.

The last thing that is easily comparable between the systems is the weight. All the components were weighted, but even though some parts have reduced their weight by 64 % or 100 %, those parts are so lightweight that the total weight reduction becomes insignificant. The total weight reduction is only 5 % and the system weight is still over 8 kg. Even if the reduction had been greater, the results could not have been used as a fact. The measured weight was of the prototype and not of the actual new system, but still, the new system is probably around 8 kg. Also the change in number of parts, going from 67 distributed on 17 different parts in the current system to 73 distributed on 16 different parts in the new system, is not remarkable.

After the validation test of the new system, a verification describing fulfilment of demands followed. Table 30 was provided to demonstrate which requirements were fulfilled and not. The list of requirements compiled in Table 19 in the case study is far longer than the one provided in Table 30, so only selected requirements were included in the fulfilment table. Due to lack of testing facility, a lot of the metrics where not tested. The picture is therefore a bit distorted. The fulfilment table gives an impression that most of the requirements were fulfilled. Most of the requirements tested were fulfilled, but the truth is that most of them were not tested at all. If the new system had been tested against all the metrics, the picture might have looked different.

In the case study several problems and issues were identified. Table 31 showed that 68 % of these issues had been solved. Most of the issues that have not been solved are unsolved because they have not been addressed. One of the issues that remain unsolved is the problem with the canvas jumping out from the canvas clamp when trying to tighten the canvas clamp. As seen in the installation test, this takes a lot of time and should be further addressed.

APPLICATION OF DFX

As mentioned previously, the design for X guidelines have been working in the background, at least throughout the entire action research. One can question if the guidelines have had a real effect when they have been working in the background as a reminder, but they were also explicitly used as evaluation criteria.

Some DfX guidelines had a big influence while others had less, but all the applied guidelines were listed in Table 32. 68 % of the applied guidelines have had a wide effect by benefitting two or more life phases or virtues. The weakness of the table is that it does not specify the extent of correlation between the guidelines and the affected DfX aspects. In reality the correlation will span from very strong to very weak, and even to negative. For example, products designed for manufacturability and assemblability tend to have fewer but more complex components, making maintenance difficult (Edwards 2002). Only positive correlations were included in this study.

The table further showed that few guidelines related to quality had been applied, but then again as described in theory Section 2.4, reliability lead to quality. One can therefore say that even though quality appears to have had little attention, it has been considered since other aspects promote it. If we look at the guidelines as small dots, we can place them into the DfX-Value relationship figure (Figure 13) and see a cloud of guidelines embracing different DfX aspects. The total number of guidelines embracing quality is more than 5, but the others act indirectly through other aspects. Design for maintainability has 11 guidelines related to it and promotes reliability. Design for reliability has 10 guidelines related to it and promotes quality additionally. With design for quality's 5 guidelines, 26 guidelines are promoting quality either directly or indirectly. In this way, it is clearer that all the guidelines contribute to the different aspects, and in turn lead to increased value.

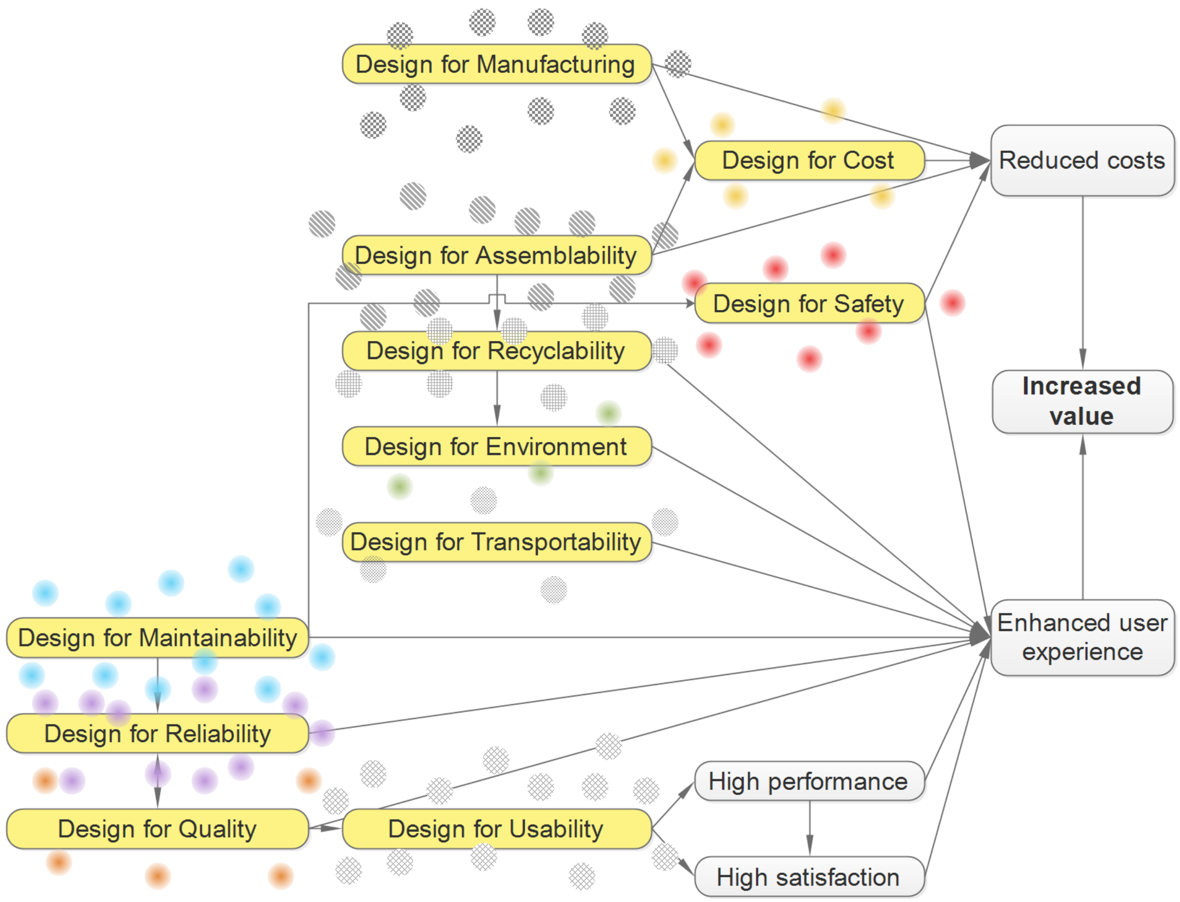


Figure 13: A cloud of DfX guidelines contributing to increased value through various DfX aspects.

One of the last statements in the action research is that there will be no problem to apply the new system in all the current product variations. It is a bold statement, but since the interfaces between the system and the other surrounding and enabling systems are mainly unchanged, there is hold in the statement. The holes for connecting the cam levers to the plate are the same holes as used for the fastening wheels, and the profile for the canvas clamps is also the same.

VALUE ADDED

There are certainly several weaknesses in the development, documentation and verification of the new system, but the test results indicate clearly that there has been an improvement.

If we look at the applied DfX guidelines listed in the Table 32, 30 qualitative design guidelines have been applied in the new system, contributing in 11 different life phases and virtues. The result of this, if we look back at the DfX-Value figure (Figure 13), is that all these guidelines contribute to enhancing the user experience or reducing cost, directly and through other DfX aspects. To be able to see who this is valuable for, we need to recall the expressed concerns of the various stakeholders.

For AquaFence it is important that the product is safe and efficient to produce, and that customer value and margins are high. They are also concerned about quality and reputation. It is furthermore important that the product solves the problem and that it is appealing so that it is easier to sell. Transforming this into DfX aspects, design for manufacturing, assemblability, cost, safety and quality is desirable for AquaFence.

The customers are on the other hand interested in low costs, high value, performance and usefulness. They also want the system to be quick to install, reliable, available, require little maintenance, safe, easy to store and possible to dispose. If the customer and the installer is the same persons, easiness and efficiency of installations and safety is also important. In DfX aspects terms, this means that design for cost, recyclability, safety, maintainability, reliability, quality and usability is desirable for the customer.

Since the 30 applied DfX guidelines cover all the aspects that the abovementioned stakeholders are concerned about, it can be stated that the use of DfX guidelines led to increased value for both customer, user and AquaFence.

And then comes the question, has the value been increased in other ways? The test results showed a decrease in installation steps of 31 % and decrease in installation time of 75 %. This means that less effort is needed while installing. Since Park (1998) defined value as the ratio of function to cost, where cost could be effort, currency or resources, the time and effort reduction increases the value for the one putting in the effort, the installer. 68 % of all the problems and issues identified were solved, and having less problems to cope with lead to less effort and hence increased value.

The test results also showed several improvements directly related to usability. The SUS score increased with 150 % and describes high satisfaction which lead to enhanced user experience (Tullis and Albert 2013) and therefore value for the user.

It is now proven that the increased usability and user experience has added value for the user and installer, but is this increase of any value for the one that pays for the system, the customer? To find the answer on this, we need to enlighten the relation between time usage and cost.

If we consider a full-scale installation with a 1000 meters of floodwall (which require 840 V2100 panels), the reduction in installation time per panel gives a total reduction of 38 hours (840 panels times 161 seconds) while using installation tools and 89 hours (840 panels times 381 seconds) without installation tools. If we assume that installation tools are available for half of the installations, the total saving would be 63 hours. These 63 hours can translate into a team of 9 persons working for 7 hours. If we further assume that one installer cost the customer EUR 30 per hour, that will give a total direct saving of EUR 1890. This saving will fluctuate heavily depending on the country and the wage level in where the panels are installed.

The improved design increases the value of the product for the customer, both from a user experience perspective, but also from a cost perspective. Also less installation errors and higher task success will increase the reliability (Kuo et al. 2001), which the customer, responsible for the area protected, is interested in. This latter value improvement is more difficult to quantify in terms of money savings.

We have now seen that the value is increased for the user and customer, but it is not so easy for AquaFence to capitalise directly on those improvements. Justifying an increase in selling price based on increased user experience is difficult. Pricing solely based on a product’s performance and appearance, and not on market needs and willingness to pay, is difficult because there are very few equivalent products in the market (Jumburgs 2015). If the new system is implemented, the value for the customer will increases without necessarily being charged more by AquaFence. The customer will receive more for the same price, and this can be beneficial in the long run (Jumburgs 2015). Garrett (2006) states that enhanced user experience will improve customer loyalty, which further can lead to more income for the company.

As stated before, the value can increase by increasing the function or experience, or reducing the cost (Park 1998), and for AquaFence that cost is production and material cost. Even though the DfX criteria design for cost was weighted among the top half in the pairwise comparison in Table 22, the costs from AquaFence' perspective has not been reduced. The new system has neither fewer parts nor easier assembly, and the parts are not proved to be cheaper. This study seems to have an asymmetrical focus between increasing value through reducing cost and enhancing the user experience. This skewed focus cannot be defended, but it might arise from mechanical engineers' natural attraction for functionality and performance in favour of economics. Nevertheless, there should be a saving potential related to production cost or materials, and this needs further assessment.

Despite the absence of reductions in production costs, there is an increase in value for AquaFence. Less effort needed in the installation and increased usability led to increased user experience which is valuable for the installer. Reduced installation time led to cost savings which is valuable for the customer. These aspects may furthermore lead to customer loyalty which is valuable for AquaFence. Also the applied DfX guidelines proved to contribute to increased value for AquaFence.

Competitive advantage through differentiation aims to provide uniqueness at something that is valuable for the customer (Porter 1998), and AquaFence is doing this by improving the user experience in various ways. A differentiation strategy is appropriate in markets where the customer are less price-sensitive, which is often the case in markets for safety systems (Ellison 2011). This market is exactly where AquaFence operates.

The increased value is beneficial in itself but contributes also to competitive advantage. So if the new system is implemented, AquaFence can keep their competitive advantage in the coming years.

5.2 Other limitations and weaknesses

The discussion highlighted several weaknesses in the development process, documentation and verification of the new system. This include among others few test persons and that several metrics were not tested. These aspects are already discussed and this section describes more general limitations and weaknesses.

When improving a product, you should be exposed to it. When I carried out the pre-master project last autumn, I visited the production site in October and used about half a day with the flood panel. That was the only exposure before I revisited the production site this May to build the suggested solution. This little exposure restricts the possibility to fully understand the product, but reading of manuals, looking at pictures and CAD-models, and discussing with company representatives helped a lot. More time handling the product physically would most likely have been beneficial.

One of the methodologies used in this thesis is the value methodology prepared by SAVE International (2007). The Value Methodology Standard states that the approach *"must be performed by a multidisciplinary team"* and that it *"must be led by a team leader trained in value methodology techniques"*. Neither of these requirements have been fulfilled, but the methodology has still been used. The standard does not say anything about consequences of not complying with these requirements, so it is difficult to quantify the extent of this limitation.

The last weak point with thesis is my own bias. I have a latent interest of proving that my solution works, and that it works better than the current solution. The verification and validation was not performed by a third party and this may have led to situations where elements in favour of my design have been excessively emphasised. I can not guarantee that information in disfavour of the selected solution has been left out.

6 Conclusion

This chapter concludes and closes the entire thesis. The chapter starts with an executive summary, including the improvements, findings and recommendations. Thereafter follows a section with a description of the objectives that have been attained. The chapters ends with proposals for further work.

6.1 Executive summary

This executive summary summarises the work that has been done, the main steps and findings. It is intended to function as an aid in decision-making processes, providing useful and concise information. The summary can be read separately from the rest of the report.

Flood related disasters in the period of 2001 - 2010 cost approximately USD 200 billion on a global level, and the frequency of flood events is steadily increasing (World Meterological Organization 2014). Along with the increase in flood events is the increase in competition among flood protection system providers. In order for AquaFence to follow the development in the market and keep their competitive advantage, improvement of their system was needed. The objective of this thesis was to holistically improve the system of connecting the flood panels, in a way that added value for the user, the customer and AquaFence. The objective was also to provide knowledge about the current system.

The thesis started by introducing several theories, including value analysis, design for X and the IPM model for product development. This was done to provide a framework for the study and to ensure a holistic approach with high quality.

Chapter 3 consisted of a case study of the current system. Stakeholders, user situations and issues with the system were identified. The fastening wheels, the canvas clamps and canvas lock sheet were identified as those parts that caused the most trouble.

User experience were tested through performance, in terms of efficiency and effectiveness, and satisfaction. The test revealed that every other installation had 1 error, that 86 % of the installation time where used at handling the fastening wheels, and that the SUS score was 35 (out of 100).

After the test, a functional analysis followed. It showed that activities related to fastening, sealing and waterproofing were the most prominent functions. It also provided a ranking table for importance of the different parts in the system. The latitudinal eccentric ranked low and have little importance compared to other parts.

The chapter and the case study ended with a set of user demand specifications and product requirement specifications, which were based on the input from the previous sections in the chapter.

Chapter 4 was an action research developing, presenting and testing a new system. The new concept arose out of inputs from the case study, design for X guidelines and a creative concept generation process. 30 solutions were generated, and they were evaluated in relation to how well they could fulfil 11 design for X aspects. These aspects had been given different weight using pairwise comparison. A concept was chosen based on the evaluation and later presented in detail and built.

The new design was tested and proved to have great improvements, both regarding performance and satisfaction. The major improvements were:

- The fastening wheels were replaced by intuitive cam lever locks, reducing the installation time with 75 %. The amount of time used on these activities were reduced by 43 percentage points.
- The need for installation tools were removed, reducing time used to correct errors with 85 %.
- The canvas lock sheet was redesigned to be smaller and less fragile, leading to fewer broken parts, fewer errors and increased task success.
- The possibility for movement in the vertical canvas clamp was removed, leading to fewer installation steps, fewer errors and increased task success.
- The latitudinal eccentric lock was removed, leading to fewer installation steps and hence higher task success.
- A logical dependency between installation steps were introduced, leading to fewer errors.
- The number of installation steps was reduced with 31 %.
- The number of errors was reduced by 57 %.
- The task success rate was increased by 4 % to 100 %.

These bullet points contributed to solve 86 % of all the identified issues and problems. This again led to an increase of 150 % in the system usability scale. Fewer installation steps and fewer errors also led to increased reliability.

The system was furthermore proved to be compatible with other product variations and was within all the product requirement specifications that was tested, except from the weight requirements. The weight reduction was only 5 %.

The discussion chapter that followed the action research highlighted several weaknesses in the study related to the development, documentation and verification of the new system. Despite that, the results from the tests are too favourable to doubt that the system has been improved.

In the design, 30 different DfX guidelines was applied, affecting 11 various DfX aspects. The use of these DfX guidelines led to increased value for both user, customer and AquaFence because these stakeholders' concerns was ensured by applying the mentioned guidelines.

Furthermore, the value was increased through performance and satisfaction for the user, the customer and AquaFence.

- **The user or installer** - Less effort and time needed in the installation, less issues to cope with and increased usability led to increased user experience which is valuable for the installer.
- **The customer -** The reduction in installation time is valuable for the customer because less personnel is needed. EUR 1890 can be saved for a 1000 meter installation if one installer cost the customer EUR 30 per hour. The increase in reliability is also valuable for the customer.
- **AquaFence.** If AquaFence keep the same selling price for the improved system, the added value will come indirectly through customer loyalty. The costs for AquaFence has not been reduced.

Based on the fact that the new system increase the value for both the user, the customer and for AquaFence, and based on the fact that there is an increasing demand within flood protection systems, it is recommended that the suggested new system is implemented by AquaFence. When doing so, Section 6.3 *Proposals for future work* should be given attention.

6.2 Objective attainment

The introductory chapter in this thesis defined some objectives. These objectives will now be reviewed one by one to see if they are attained.

I. *Contribute to the research and development collaboration between AquaFence and NTNU by providing in-depth knowledge and analysis of the current connection system.*

Chapter 3 was a case study analysis reviewing and analysing the current system. A lot of information regarding functionality, stakeholders, user situations, problems and issues was provided, but all this information is already known for AquaFence. Their possession of the information is not organised in the same way, but they are aware of all the concerns. On the other hand, Chapter 3 also provides information and knowledge that is new for AquaFence. The in-depth functional analysis is one example of that, providing valuable insight in the product. The installation tests of performance and satisfaction, providing installation times, error rates and a SUS score, is also new and valuable information for AquaFence. The chapter ended with a set of specifications. These were a translation of the previous sections, and in that way not necessarily new information, but it was wrapped in a new way providing new perspectives. The first objective is considered attained.

II. *Improve the connection system from a holistic perspective using design for X strategies.*

This second objective is twofold. "*Improving the system"* and *"doing this in a holistic perspective using DfX"*. The discussion showed that the installation time, time used on correcting errors, number of installation steps and error rate was reduced. Success rate and SUS score was increased. In addition to this, the need for installation tools were removed. The system was absolutely improved, but was it done in a holistic perspective? The DfX way of thinking was present throughout the development phases in the action research. More explicitly, the 11 DfX life phases and virtues were used as evaluation criteria and the generated concepts were evaluated for how well they could fulfil these aspects. This is a holistic approach because a concept would not obtain a high score if it only had addressed one of the life phases or virtues. By providing a list of 30 qualitative DfX guidelines that have been implemented in the system, Table 32 in the verification part proved that a DfX approach had been used. The second objective is considered attained.

III. *Develop a redesign for the connection system that provides additional value for AquaFence, customers and users.*

Figure 13 in the discussion showed how the design guidelines directly and through other DfX aspects contributed in enhancing the user experience or reducing cost, and hence increasing the value. Since the guidelines covered all the DfX aspects that AquaFence, customers and users were concerned about, the use of DfX guidelines led to increased value. Value was furthermore added for the user and installer through providing less effort and time needed in the installation, less issues to cope with, increased usability and hence increased user experience. Value was added for the customer by saving installation personnel and increasing reliability. Lastly, value was added indirectly for AquaFence through the potential of increased customer loyalty. The third objective is considered attained.

IV. Reduce the installation time for the connection system.

One of the improvements that led to attainment for objective II was the reduction in installation time. The installation time was reduced by 75 % and objective IV is also considered attained.

As seen in this section, all the defined objectives has been attained with a wide margin.

6.3 Proposals for future work

If the suggested new system in this thesis is to be successfully implemented and benefits from the design obtained, further work is needed.

First of all, AquaFence needs to decide if the suggested solution for a new system is worth implementing. The executive summary in Section 6.1 will be useful in taking that decision. In such a decision, resources must be allocated to execute the implementation project.

Secondly, AquaFence needs to evaluate if any adjustment or supplements are needed in the proposed design. Section 4.4.3 *Compliance with current problems in the new system* describes issues that are yet to be solved, including thickness of the system when folded, wires snagging and access to the uppermost cam lever, and is a good place to look for this.

Another area that can be address for further improvement is the activity and method for sliding the canvas underneath the canvas clamps. This is the most time consuming activity task and stands for 46 % of the installation time in the new system. Also the costs for AquaFence related to the product and production should be given attention in order to increase the value in a more direct way.

As mentioned in the discussion, the testing was imperfect, and more tests should be conducted. The tests should involve a line of V2100 panels exposed to rising water, performed by several different installers.

When AquaFence is satisfied with the design, they should proceed to the third and final stage in the value study, the post-workshop dealing with implementation. Parallel with this stage is the fifth and final phase in the IPM model, the preparation for production phase.

7 References

Anderson, E. W., Fornell, C. & Lehmann, D. R. 1994. Customer Satisfaction, Market Share, and Profitability: Findings from Sweden. *Journal of Marketing,* 58**,** 53-66.
AquaFence. 2014a. *Perimeter Flood Protection* [Online]. Available: http://aquafence.com/int/perimeter-flood-protection/ [Accessed 16.10. 2014].
AquaFence 2014b. Perimeter Flood Protection Barrier System - Product Manual. AquaFence AS.
AquaFence. 2014c. *Projects* [Online]. AquaFence AS. Available: http://aquafence.com/int/projects/ [Accessed 15.11.2014.
Asiedu, Y. & Gu, P. 1998. Product life cycle cost analysis: State of the art review. *International Journal of Production Research,* 36**,** 883-908.
Bahrami, A. & Dagli, C. H. 1993. Models of design processes. *In:* Parsaei, H. R. & Sullivan, W. G. (eds.) *Concurrent Engineering: Contemporary Issues and Modern Design Tools.* Springer Science & Business Media.
Baroto, M. B., Abdullah, M. M. B. & Wan, H. L. 2012. Hybrid strategy: a new strategy for competitive advantage. *International Journal of Business and Management,* 7**,** 14.
Bauer, S. & Paetzold, K. 2006. Influence of DFX criteria on the design of the product development process. *6th Integrated Product Development Workshop (IPD).* Magdeburg, Germany.
Baykasoglu, A. 2014. A review and analysis of "graph theoretical-matrix permanent" approach to decision making with example applications. *Artificial Intelligence Review,* 42**,** 573-605.
Baylin, E. N. 1990. *Functional Modeling of Systems,* Amsterdam, Gordon and Breach Science Publishers.
Bevilacqua, M., Ciarapica, F. E. & Giacchetta, G. 2012. Integration of Design for Environmental Concepts in Product Life Cycle. *Design for Environment as a Tool for the Development of a Sustainable Supply Chain.* London: Springer.
Biggioggero, G. F. & Rovida, E. 1996. Design for Quality. *In:* Huang, G. Q. (ed.) *Design for X: concurrent engineering imperatives.* London: Chapman & Hall.
Bjerkholt, J. T. & Lindholm, O. G. 2007. An Innovative Semi-permanent Flood Protection Structure - Alternative to Sandbags and Supplements to Conventional Earth Embankments. *Advances in Urban Flood Management.* Taylor & Francis.
Bjork, J. 2013. Aquafence Installation, Removal and Operating Manual. *In:* Jumburgs, E. (ed.) 1.2 ed.: AquaFence.
Blanchard, B. S. 2011. *Systems engineering and analysis,* Boston, Pearson.
Brooke, J. 1996. SUS: a 'quick and' dirty usability scale. *In:* Jordan, P. W. T., B., McClelland, I. L. & Weerdmeester, B. (eds.) *Usability evaluation in industry.* London: Taylor & Francis.
Browning, T. R. 2003. On customer value and improvement in product development processes. *Systems Engineering,* 6**,** 49-61.
Center for Innovation in Research and Teaching. 2012. *Basic Research Design* [Online]. Grand Canyon University,. Available: https://cirt.gcu.edu/research/developmentresources/tutorials/researchdesigns [Accessed 10.04 2015].
Checkland, P. 1999. *Systems thinking, systems practice,* John Wiley.
Chevron Corporation 2008. Hazard Identification tool. Chevron Energy Technology Company.

Chiu, I. & Salustri, F. A. Evaluating design project creativity in engineering design courses. The 1st CEEA Conference, 7.-9.06. 2010 Queen's University Kingston, Ontario, Canada. Canadian Engineering Education Association Conference.

Ciechanowski, P., Malinowski, L. & Nowak, T. 2007. DFX Platform for life-cycle aspects analysis. *In:* Loureiro, G. & Curran, R. (eds.) *Complex Systems Concurrent Engineering.* Springer London.

Clarkson, J. & Eckert, C. 2005. *Design process improvement: A review of current practice,* London, Springer London.

Crow, K. A. 2002. *Value Analysis and Function Analysis System Technique* [Online]. DRM Associates. Available: http://www.npd-solutions.com/va.html [Accessed 10.02 2015].

Dahl, F. 07.10 2014. *RE: Personal communication.*

Dalsgaard, H. V. 2014. *A Systematic Value Analysis and Design Improvement of AquaFence's Mobile Flood Protection System.* Pre-Master, Norwegian University of Science and Technology.

De Vaus, D. A. 2001. What is Research Design? *Research design in social research.* London: Sage Publications Ltd.

Dombrowski, U., Schmidt, S. & Schmidtchen, K. 2014. Analysis and Integration of Design for X Approaches in Lean Design as basis for a Lifecycle Optimized Product Design. *Procedia CIRP*, 15**,** 385-390.

Dowlatshahi, S. 1996. The role of logistics in concurrent engineering. *International Journal of Production Economics*, 44**,** 189-199.

Edwards, K. L. 2002. Towards more strategic product design for manufacture and assembly: priorities for concurrent engineering. *Materials & Design*, 23**,** 651-656.

Ellison, B. 2011. *MTA: Reliability or price, what matters most?* [Online]. Panbo.com. Available: http://www.panbo.com/archives/2011/05/mta_reliability_or_price_what_matters_most.html [Accessed 10.05. 2015].

Garrett, J. J. 2006. Customer Loyalty and the Elements of User Experience. *Design Management Review*, 17**,** 35-39.

Gatenby, D. A. & Foo, G. 1990. Design for X (DFX): Key to competitive, profitable products. *AT&T Technical Journal*, 69**,** 2-13.

Grave, J. H. L. 2013. *TMM4115 Produktmodellering TMM4121 Produktutvikling,* Trondheim, Akademika Forlag.

Haines, S. G. 2006. *How to Work with Executives - The Systems Thinking Approach*, Systems Thinking Press.

Halpin, V. 2003. Verification vs Validation. International ISO Group.

Haskins, C. 2014. Systems engineering - both a discipline and a method. Norwegian University of Science and Technology.

Heylighen, F. 1998. *Basic Concepts of the Systems Approach* [Online]. Brussels: Principia Cybernetica. Available: http://pespmc1.vub.ac.be/sysappr.html [Accessed 18.02 2015].

Hirschheim, R. 1992. Information Systems Epistemology: An Historical Perspective. *In:* Galliers, R. (ed.) *Information Systems Research: Issues, Methods and Practical Guidelines.* London: Blackwell Scientifc Publications.

Holt, R. & Barnes, C. 2009. Towards an integrated approach to "Design for X": an agenda for decision-based DFX research. *Research in Engineering Design*, 21**,** 123-136.

Huang, G. Q. 1996. *Design for X: concurrent engineering imperatives,* London, Chapman & Hall.

International Council on Systems Engineering 2012. *Systems Engineering Handbook, version 3.2.2*, San Diego, California, International Council on Systems Engineering (INCOSE).
International Organization for Standardization 1998. Ergonomic requirements for office work with visual display terminals (VDTs) *Guidance on usability (ISO 9241-11:1998).* Standard Norge.
International Organization for Standardization 2011. Ergonomics of human-system interaction. *Human-centred design for interactive systems (ISO 9241-210:2010).* Standard Norge.
International Organization for Standardization (ISO), International Electrotechnical Commission (IEC) & Institute of Electrical and Electronics Engineers (IEEE) 2008. Systems and Software Engineering - System Life Cycle Processes. *ISO 15288:2008.* Geneva, Switzerland: International Organization for Standardization (ISO).
Jelierse, R. & van der Vegte, W. 2008. *Function analysis* [Online]. Delft University of Technology. Available: http://www.wikid.eu/index.php/Function_analysis [Accessed 10.02 2015].
Jumburgs, E. 10.03. 2015. *RE: Personal communication.*
Kuo, T.-C., Huang, S. H. & Zhang, H.-C. 2001. Design for manufacture and design for 'X': concepts, applications, and perspectives. *Computers & Industrial Engineering,* 41**,** 241-260.
Lindemann, U. 2007. A Vision to Overcome "Chaotic" Design for X Processes in Early Phases. *International Conference on Engineering Design.* Paris.
Luttropp, C. & Lagerstedt, J. 2006. EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development. *Journal of Cleaner Production,* 14**,** 1396-1408.
Manikutty, S. 2011. *Being Ethical: Ethics as the Foundation of Business*, Random House India.
Maropoulos, P. G. & Ceglarek, D. 2010. Design verification and validation in product lifecycle. *CIRP Annals - Manufacturing Technology,* 59**,** 740-759.
Meerkamm, H. & Koch, M. 2005. Design for X. *In:* Clarkson, J. E., Claudia (ed.) *Design process improvement - A review of current practice.* London: Springer.
Mital, A., Desai, A., Subramanian, A. & Mital, A. 2014. Chapter 10 - Design for Usability. *Product Development.* 2nd ed. Oxford: Elsevier.
National Severe Storms Laboratory. 2012. *Flood basics* [Online]. Norman, USA. Available: http://www.nssl.noaa.gov/education/svrwx101/floods/ [Accessed 08.12 2014].
Nieswiadomy, R. M. 2008. Qualitative Research Designs. *Foundations of nursing research.* 5 ed. New Jersey: Prentice Hall.
O'Brien, R. 1998. *An Overview of the Methodological Approach of Action Research* [Online]. Brazil: Universidade Federal da Paraíba. Available: http://web.net/robrien/papers/arfinal.html [Accessed 19.05. 2015].
Organisation for Economic Co-operation and Development 2002. *Frascati Manual 2002: Proposed Standard Practice for Surveys on Research and Experimental Development,* Paris, OECD Publishing.
Pahl, G., Beitz, W., Feldhusen, J. & Grote, K.-H. 2007. *Engineering Design: A Systematic Approach,* London, Springer.
Paramasivam, V. & Senthil, V. 2009. Analysis and evaluation of product design through design aspects using digraph and matrix approach. *International Journal on Interactive Design and Manufacturing (IJIDeM),* 3**,** 13-23.
Park, R. 1998. *Value Engineering: A Plan for Invention*, Taylor & Francis.

Porter, M. E. 1998. *Competitive Advantage: Creating and Sustaining Superior Performance,* New York, Free Press.
Rausand, M. & Utne, I. B. 2009. Product safety – Principles and practices in a life cycle perspective. *Safety Science,* 47**,** 939-947.
Saha, P. 2013. *A Systemic Perspective to Managing Complexity with Enterprise Architecture*, IGI Global.
Salustri, F. 2005. *Pairwise Comparison* [Online]. Designwiki. Available: http://deseng.ryerson.ca/dokuwiki/design:pairwise_comparison?do= [Accessed 18.04. 2015].
Sauro, J. 2011. *Measuring usability with the system usability scale (SUS)* [Online]. Measuring Usability LLC. Available: http://www.measuringu.com/sus.php [Accessed 18.11. 2014].
SAVE International 2007. Value Methodology Standard and Body of Knowledge. SAVE International.
Shuttleworth, M. 2008. *Case Study Research Design* [Online]. Explorable.com. Available: https://explorable.com/case-study-research-design [Accessed 19.05. 2015].
Strøm-Gundersen, T. 2007. *Dropper mobilt flomvern* [Online]. Teknisk Ukeblad Media AS. Available: http://www.tu.no/industri/2007/08/30/dropper-mobilt-flomvern [Accessed 05.10. 2014].
Tarr, M. 2007. *The DfX concept* [Online]. Available: http://www.ami.ac.uk/courses/topics/0248_dfx/ [Accessed 22.09. 2014].
Tullis, T. & Albert, B. 2013. *Measuring the user experience: Collecting, analyzing, and presenting usability metrics,* Amsterdam, Netherlands, Elsevier.
Usability.gov. 2013a. *System Usability Scale (SUS)* [Online]. U.S. Department of Health & Human Services. Available: http://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html#PAGE_4 [Accessed 18.11 2014].
Usability.gov. 2013b. *Usability Evaluation Basics* [Online]. U.S. Department of Health & Human Services. Available: http://www.usability.gov/what-and-why/usability-evaluation.html [Accessed 01.12 2014].
Van der Voordt, T. & Lans, W. 2002. Descriptive research. *In:* van der Voordt, D. J. M. & de Jong, T. M. (eds.) *Ways to study and research: urban, aechitectural and technical design.* Delft: Delft University Press.
Walonick, D. S. 1993. *General Systems Theory* [Online]. StatPac Survey Research Library. Available: http://www.statpac.org/walonick/systems-theory.htm [Accessed 19.02. 2015].
Warwick Manufacturing Group 2007. Design for X. *Product Excellence using 6 Sigma (PEUSS).* Warwick: University of Warwick.
Watson, D. & Adams, M. 2010. Flooding. *Design for Flooding.* John Wiley & Sons Inc.
World Meterological Organization 2014. Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes. Geneva, Switzerland: World Meterological Organization.

8 Appendix

8.1 Task description from the institute

THE NORWEGIAN UNIVERSITY
OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF ENGINEERING DESIGN
AND MATERIALS

MASTER THESIS SPRING 2015
FOR
STUD.TECHN. Henrik Vagle Dalsgaard

Redesign and implementation of design improvements to flood protection system
Redesign og implementering av designendringer for flomvernsystem

AquaFence is a Norwegian company that develops and manufactures a mobile flood protection system which is certified and tested according to international standards. Although the existing system is currently leading in the market place, competition is steadily increasing. It is therefore essential to improve the existing product system to sustain the technologically competitive edge in the future.

AquaFence flood protection system is designed to withstand flood heights up to 210 cm. Today's flood protection has a very high structural safety factor, e.g. as a result of conservative assumptions / methods used for dimensioning. This has resulted in the use of expensive materials, partly oversized geometry and also to some extent non-optimal solutions, and thus high weight and cost. The system also has relatively many parts and fasteners. Moreover, it is relatively time-consuming to produce and sets high standards for quality assurance in the internal assembly process.

In this MSc work, the candidate will be studying opportunities to improve selected design elements/subsystems from a holistic perspective using Design for X strategies. A substantial pre-work has been conducted throughout the candidate's project during the fall of 2014, and the MSc thesis will build on the results and conclusion from the previous work. The overall business objective is to develop a redesigned product that provides additional value.

The objective of the study is to identify and redesign selected elements of the flood protection system, including the solution used for connecting the flood panels and the canvas clamps identified in the abovementioned project work.
The thesis will include:

1. To establish a detailed description of today's solution and related problems.
2. To perform a synthesis and analysis of needs, requirements, possible solutions, etc.
3. To design and select an improved solution.
4. To build of test panels/prototypes based on the new solution
5. To design a test procedure for validation of performance.
6. To evaluate and test of the new panels, and compare with today's solutions.
7. To quantify improvement potential (benefit and cost) as compared to existing system.

Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Masteroppgave" (http://www.ntnu.no/ipm/masteroppgave). This sheet should be updated one week before the master's thesis is submitted.

Risk assessment of experimental activities shall always be performed. Experimental work defined in the problem description shall be planed and risk assessed up-front and within 3 weeks after receiving the problem text. Any specific experimental activities which are not properly covered by the general risk assessment shall be particularly assessed before performing the experimental work. Risk assessments should be signed by the supervisor and copies shall be included in the appendix of the thesis.

The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.

The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's theses.

The contact person is Fred Dahl, Aquafence.

Torgeir Welo
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Torgeir Welo
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NTNU
Norges teknisk-
naturvitenskapelige universitet
Institutt for produktutvikling
og materialer

8.2 Risk analysis of the project

NTNU HMS	Kartlegging av risikofylt aktivitet	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av	Side	Erstatter
		Rektor	1 av 2	01.12.2006

Enhet: **IPM** **Dato: 09.02.2015**

Linjeleder:

Deltakere ved kartleggingen (m/ funksjon)**: Student**
(Ansv. veileder, student, evt. medveiledere, evt. andre m. kompetanse)

Kort beskrivelse av hovedaktivitet/hovedprosess: Masteroppgavestudent Henrik Vagle Dalsgaard. «Redesign and implementation of design improvements to flood protection system».

Er oppgaven rent teoretisk? (JA/NEI)**: NEI** *«JA» betyr at veileder innestår for at oppgaven ikke inneholder noen aktiviteter som krever risikovurdering. Dersom «JA»: Beskriv kort aktiviteteten i kartleggingskjemaet under. Risikovurdering trenger ikke å fylles ut.*

Signaturer: *Ansvarlig veileder:* *Student:*

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Fabrikkbesøk i Latvia	Student		Nasjonale og EU-relaterte krav og retningslinjer.		
2	Reise i forbindelse med prosjekt	Student		Nasjonale, internasjonale og EU-relaterte krav og retningslinjer.	Internasjonale og nasjonale lover	
3	Verkstedsarbeid	Student		Retningslinjer for bruk av verksted		
4	Tunge løft	Student				

NTNU HMS	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av	Side	Erstatter
		Rektor	2 av 2	01.12.2006

Enhet: **IPM** **Dato: 09.02.2015**

Linjeleder:

Deltakere ved kartleggingen (m/ funksjon): Student
(Ansv. Veileder, student, evt. medveiledere, evt. andre m. kompetanse)

Risikovurderingen gjelder hovedaktivitet: Masteroppgavestudent Henrik Vagle Dalsgaard. «Redesign and implementation of design improvements to flood protection system»

Signaturer: *Ansvarlig veileder:* Torgeir Welo *Student:* Henrik V. Dalsgaard

ID nr	Aktivitet fra kartleggings-skjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sannsyn-lighet (1-5)	Vurdering av konsekvens: Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)	Risiko-Verdi (menn-eske)	Kommentarer/status Forslag til tiltak
1	Fabrikkbesøk i Latvia	Fall, truffet av last etc.	3	C				3C	Følge fabrikkens rutiner og retningslinjer
2.1	Reise i forbindelse med prosjekt	Flykrasj/terror	1	E				1E	Bruke anerkjente transportselskap
2.2	Reise i forbindelse med prosjekt	Bil-/busskrasj	2	D				2D	Bruke anerkjente transportselskap og være bevisst på egen bilkjøring.
3.1	Verkstedsarbeid	Personskade ved bruk av maskiner	2	D					Bruke påkrevd værneutstyr. Utøve forsiktighet
3.2	Verkstedsarbeid	Miste tunge gjenstander på føtter/hender	3	B					Utøve forsiktighet.
4	Tunge løft	Ryggskade	3	C					God løftestilling. Bruke mekanisk løfteanordninger

8.3 Sample of cost drivers

Table 3 Sample cost drivers

Life cycle	Products	Processes	Resources
Design & development	# of parts in a product % of common, standard, or unique parts Shape, depth and width of bills of materials # of new products introduced each year	# of review / check points # of design change notices % of back orders	# of pages of drawings (A4 equivalent) # of drawing errors
Purchasing	# of "buy" parts # of purchase orders # of raw materials	# of supply expedites # of inspections of incoming materials # of supplier visits	# of suppliers
Production planning & Shop-floor manufacture	# of manufacturing features # of "make" parts # of reworks # of scraps	# of operations # of processes # of production orders # of schedule changes # of engineering change requests # of setups # of changeovers	# of machines # of part movements # of tools and fixtures # of tool movements
Inspection and test	# of parts to be inspected # of key characteristics being inspected	# of inspections # of defects / faults	# of check points # of special test / inspection equipment # of inspectors
Storing & shipping	Product size, shape, weight etc.	# of movements distance of movements	# of tablets pallet space
Sales and marketing	# of product models # of product variants in a model # of cancellations # of defects recalled	# of order changes # of promotions and surveys # of customer order expedites	# of new customers # of customers withdrawn # of sales orders / invoices # of customer enquiries
Installation	# of components to be installed	# of installation operations	# of special tools
Use & operation	# of panel controls # of safety devices	# of operator movements	# of operators space requirements
Service & repair	# of customer complaints # of site service visits	# of service operations	# of tools # of special skills
Recycling & disposal	# of parts recyclable # of parts disassemble	# of disassembly operations	# of disassembly tools and equipment

(Huang 1996, p. 10)

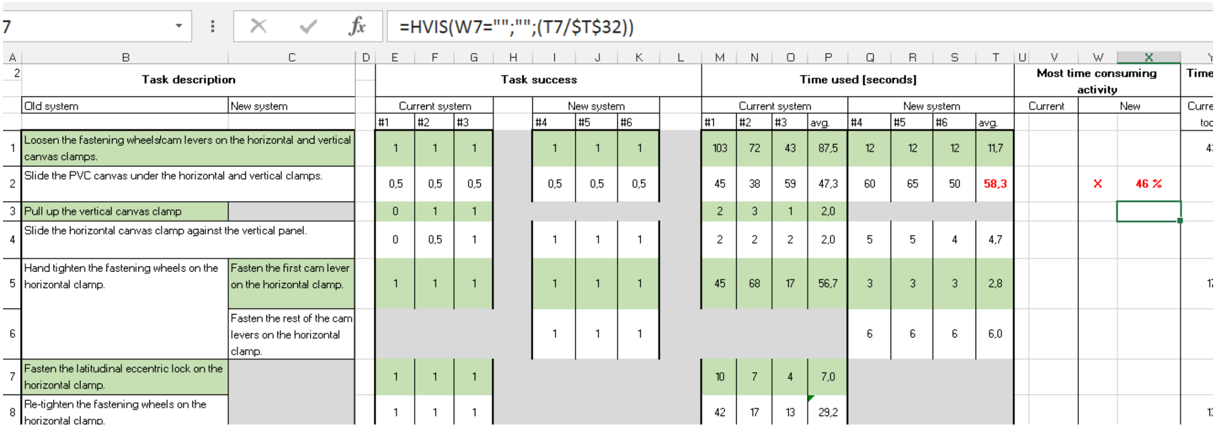
8.4 System Usability scale questionnaire

	Strongly disagree				Strongly agree
	1	2	3	4	5
1. I think that I would like to use this system frequently.					
2. I found the system unnecessarily complex.					
3. I thought the system was easy to use.					
4. I think that I would need the support of a technical person to be able to use this system					
5. I found the various functions in this system were well integrated.					
6. I thought there was too much inconsistency in this system.					
7. I would imagine that most people would learn to use this system very quickly.					
8. I found the system very cumbersome to use.					
9. I felt very confident using the system.					
10. I needed to learn a lot of things before I could get going with this system.					

(Brooke 1996)

8.5 Calculations of installation times and task success

The file is delivered in a zipped file through DAIM, together with the digital version of this thesis. The file is named “8.5 Calculations of installation times and task success”. It can also be accessed through this link bit.ly/aquafence2015, using the password aquafence2015. The file is not fully compatible with versions of Excel older than 2013.



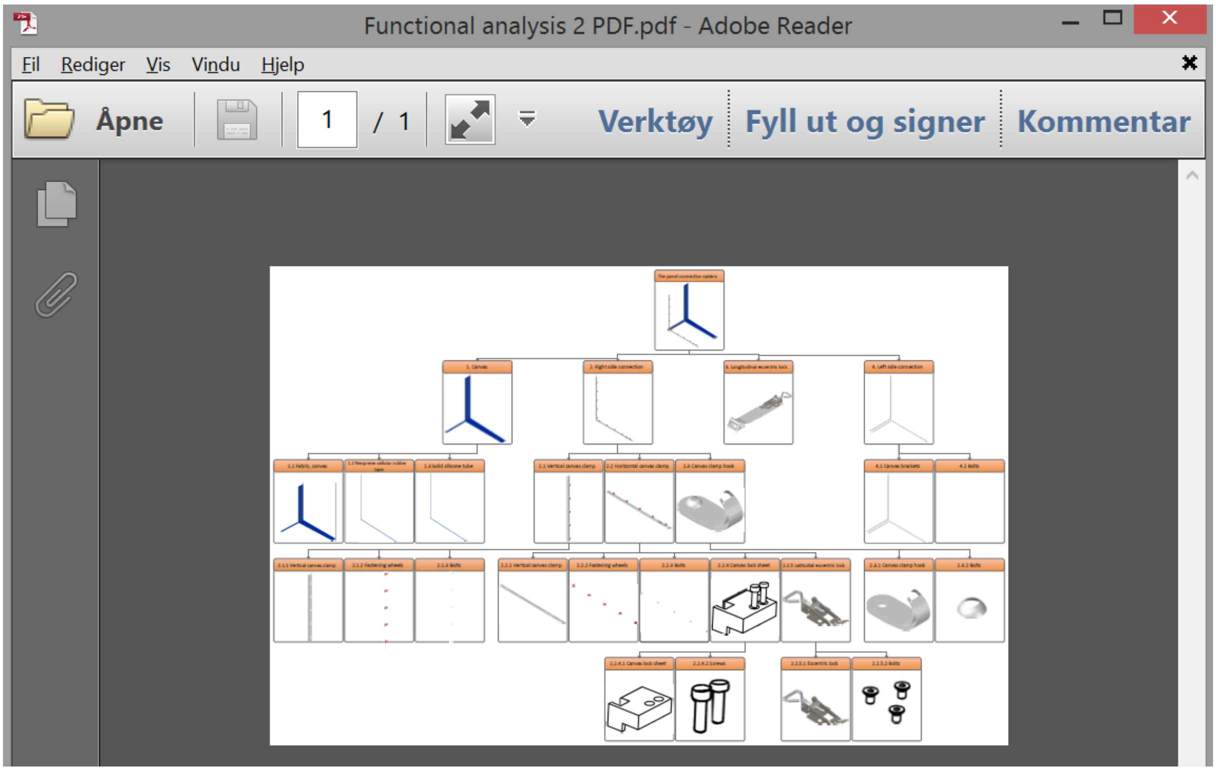
7 | =HVIS(W7="";"";(T7/$T$32))

2	Task description		Task success						Time used [seconds]								Most time consuming activity		Time
	Old system	New system	Current system			New system			Current system				New system				Current	New	Curre
			#1	#2	#3	#4	#5	#6	#1	#2	#3	avg.	#4	#5	#6	avg.			toc
1	Loosen the fastening wheels/cam levers on the horizontal and vertical canvas clamps.		1	1	1	1	1	1	103	72	43	87,5	12	12	12	11,7			4
2	Slide the PVC canvas under the horizontal and vertical clamps.		0,5	0,5	0,5	0,5	0,5	0,5	45	38	59	47,3	60	65	50	58,3		× 46 %	
3	Pull up the vertical canvas clamp		0	1	1				2	3	1	2,0							
4	Slide the horizontal canvas clamp against the vertical panel.		0	0,5	1	1	1	1	2	2	2	2,0	5	5	4	4,7			
5	Hand tighten the fastening wheels on the horizontal clamp.	Fasten the first cam lever on the horizontal clamp.	1	1	1	1	1	1	45	68	17	56,7	3	3	3	2,8			1
6		Fasten the rest of the cam levers on the horizontal clamp.				1	1	1					6	6	6	6,0			
7	Fasten the latitudinal eccentric lock on the horizontal clamp.		1	1	1				10	7	4	7,0							
8	Re-tighten the fastening wheels on the horizontal clamp.		1	1	1				42	17	13	29,2							1

Picture 57: Screenshot from excel file

8.6 Functional analysis

The high resolution PDF file of the functional analysis is delivered in a zipped file through DAIM, together with the digital version of this thesis. The file is named “Appendix - 8.6 Functional analysis.pdf”. It can also be accessed through this link bit.ly/aquafence2015, using the password aquafence2015.



8.7 Calculations for concept evaluation

The file is delivered in a zipped file through DAIM, together with the digital version of this thesis. The file is named “Appendix - 8.7 Calculations for concept evaluation”. It can also be accessed through this link bit.ly/aquafence2015, using the password aquafence2015.The file is not fully compatible with versions of Excel older than 2013

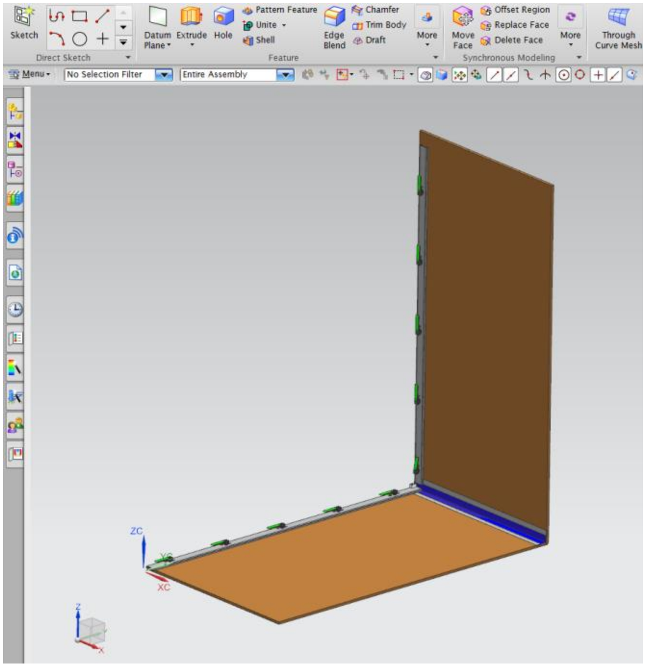
O4 =HVIS(O3=0;'Weight and scales'!$D$18;(HVIS(O3=1;'

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1				Quality	Cost	Environment	Safety	Maintainability	Reliability	Manufacturability	Assemblability	Transportability	Usability	Recyclability	Uncertainty [0-4]	Sum	**Total score**
2			Weight→	15	11	2	16	6	16	7	5	5	12	3			
3		Zipper	A	3,0	4,5	4,0	5,0	5,0	3,0	5,0	5,0	3,5	6,0	5,0	2,00	49,0	**389**
4				46	49	7	82	32	49	36	27	19	71	14	0,90	432,7	
5		2x zipper	B	3,5	3,5	4,0	5,0	4,5	4,0	4,0	4,0	3,5	5,0	5,0	3,00	46,0	**355**
6				54	38	7	82	29	65	29	22	19	59	14	0,85	418,2	
7		Maxigrip	D	5,0	4,0	5,0	5,0	4,5	4,0	5,0	5,0	3,5	6,0	5,0	1,00	52,0	**450**
8				77	44	9	82	29	65	36	27	19	71	14	0,95	473,2	
9		Magnet strip	E	4,0	4,0	4,0	5,0	2,5	4,0	5,0	5,0	3,5	5,0	4,0	2,00	46,0	**386**
10				62	44	7	82	16	65	36	27	19	59	11	0,90	428,6	

Picture 58: Screenshot from the excel file

8.8 CAD-models of the new system

The files are delivered in a zipped file through DAIM, together with the digital version of this thesis. The files are inside the folder "8.8 CAD-models of the new system", and the master file is called "assembly1.prt". The files can also be accessed through this link bit.ly/aquafence2015, using the password aquafence2015. The parts are modelled using Unigraphics NX 9.0, and might not be compatible with earlier versions of the software.



Picture 59: Screenshot from the modelling interface in Unigraphics NX