New Passdoor for Fix Panel Industrial Gates

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MASTER THESIS

New Passdoor for Fix Panel Industrial Gates

Research & development for a New Pedestrian Side Door for Industrial Environments

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Abstract

This Master Thesis, executed in collaboration with ASSA ABLOY Entrance Systems, focused on designing a new and improved secondary entrance for overhead panel industrial gates, which is part of the existing product line. The secondary entrance developed in this project is called a Passdoor, which is placed in a fixed section next to the gate and is used to separate pedestrian traffic through the industrial gate from vehicles and deliveries. The end goal of the project was to finalize the design of a Passdoor with variable dimensions in two thickness configurations.

To achieve this goal, the Master Thesis followed the steps of a well-established theoretical product development process, called the double diamond process. This included both deep research in the project, as well as a extensive design process characterized by an iterative human centered design process. This included repeating observation, ideation, prototyping and testing to develop a well thought out final solution.

The result is a new and standardized door, that fits well into the ASSA ABLOY product ecosystem. The design allows for doors produced with an unlimited variation of dimensions in height and width within an allowable range, but is standardized as far as possible to reduce design and engineering cost for every produced door.

In this Master Thesis it is concluded that the new Passdoors might very well be part of the company's future product line and particularly attractive for customers interested in implementing an additional secondary entrance to their overhead industrial gates.

Keywords: Product development, Assa Abloy, Passdoor, Industrial doors, Solid mechanics

Sammanfattning

Detta examensarbete, genomfört i samarbete med ASSA ABLOY Entrance Systems, fokuserade på att design en ny och förbättrad sekundär ingång för industriportar, som en utökning av den befintliga produktlinjen. Den sekundära ingången som utvecklats i detta projekt kallas Passdoor, som placeras i en fast sektion bredvid porten och används för att separera gångtrafik genom industriporten från fordon och leveranser. Slutmålet med detta projekt var att slutföra utformningen av en Passdoor med varierande dimensioner i två tjocklekskonfigurationer.

För att uppnå detta mål följde examensarbetet stegen i en väletablerad teoretisk produktutvecklingsprocess, kallad the Double Diamond Process. Detta omfattade både djupgående efterforskning inom projektet, samt en omfattande designprocess som kännetecknades av en iterativ mänskligt centrerad designprocess. Detta inkluderade upprepade observationer, idéer, prototypskapande och tester för att utveckla en genomtänkt slutgiltig lösning.

Resultatet är en ny och standardiserad dörr som passar väl in i ASSA ABLOY's etablerade produktkatalog. Designen möjliggör att dörrar kan produceras med en obegränsad variation av dimensioner i höjd och bredd inom ett tillåtet intervall, men är så långt som möjligt standardiserat för att minska design och konstruktions-kostnader för varje enskild producerad dörr.

I detta examensarbete dras slutsatsen att den nyutvecklade Passdoor mycket väl kan vara en del av företagets framtida produktlinje och särskilt attraktiv för kunder som är intresserade av att implementera en extra sekundär ingång till sina industriportar.

Nyckelord: Produktutveckling, Assa Abloy, Sidodörr, Industridörrar Hållfasthetslära

Acknowledgments

Firstly, in this Master Thesis, I would like to express my great appreciation to all the people who have contributed to this project. Without support and help, this could not have been possible.

Firstly, I would like to thank all the people employed at ASSA ABLOY Entrance Systems for all support, guidance and help with even the most stupid of questions. Thank you for your insight and help; Marcel Ligthart, Johanna Sjöberg, Linus Bäcklund, Peter Sundqvist, Bjarne Larsson & Michael Nerheden.

I would also like to express my gratitude to my fellow co-workers at ASSA ABLOY Entrance Systems, including other Master Thesis-workers and summer interns with extensive help, support and expertise during the project. This includes everything from advanced skills 3D-printing, to help using modelling software and measuring door handles. Thank you very much; Patrik Zitny, Johan Möllerström, Patrik Johansson, Oscar Sundbom, Elin Elfström & Michelle Atlas.

A special thank you goes to my supervisor at ASSA ABLOY Entrance Systems in Landskrona, Anders Löfgren. Anders was not only extremely valuable as the individual providing the scope of the Master Thesis from the start, seeing my potential and being willing to adapt the project to fit both of our goals. Despite being up to his ears in work from time to time, Anders always puts on a happy face and spreads a good atmosphere among his co-workers.

In addition, I would like to thank teachers and others employed at The Faculty of Engineering at Lund's University who have contributed to this Master Thesis. Thank you; examinator Glenn Johansson and supervisor Per Liljeqvist for guidance. A special thank you goes to teacher Per-Erik Andersson, who helped with profound expertise in mechanics calculations and Håkan Hallberg for his extensive knowledge and will to always help with troubles in solid mechanics.

Finally, I would like to direct a big thank you to all of my family and friends, who have always provided support and a helping hand during my studies. A special thank you goes to Christian and Catharina Schulz and Johanna Sjöblom for always being there.

Landskrona, August 11th, 2021

Jonathan Schulz

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In theory, there is no difference between theory and practice.

In practice, there is. (Norman, 2013)

1 Introduction

The scope of the project, problem formulation, goals and mission statement of the Master Thesis is presented in the introduction section together with background about the company, student and others involved in the project.

1.1 Problem description

ASSA ABLOY Entrance Systems is today one of the leading companies in design and manufacturing of industrial doors and gates. One of the main products that the company sells is an industrial gate built out of panels placed inside a metallic frame, which rolls upwards when being opened. The gate is offered in two thicknesses to accommodate for the customers insulation needs, 42mm and 82mm with the product names OH1042P and OH1082P respectively. Examples of how this product might look is shown in Figure 1.1.

Figure 1.1 - Examples of overhead industrial gates produced by ASSA ABLOY Entrance Systems.

In industrial environments though, there is often a need for a secondary passage related to the gate. This is both to separate humans from industrial vehicles passing through the gate, but also for insulation purposes since opening a smaller door generates less heat leakage than the larger gate every time a person passes. This secondary passage is called a Passdoor. The Passdoor can be placed separately from the gate, incorporated into the gate and in a fixed section inside the gate opening but besides the primary gate. The last variant of a Passdoor is what needs to be designed in this project. A previous design of this fixed section Passdoor is shown in Figure 1.2.

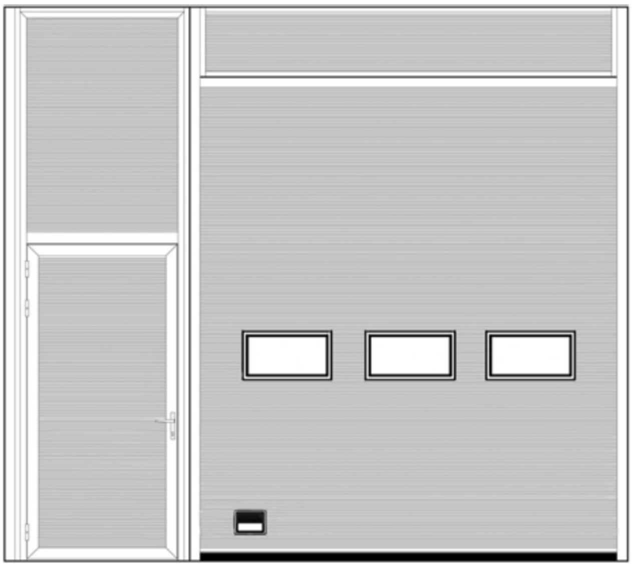

Figure 1.2 - Industrial gate section, with a previous ASSA ABLOY designed Passdoor placed in a fixed section at the left side of the gate.

Passdoors for ASSA ABLOY's panel-based industrial gates are available on the market, as seen in two of the images in Figure 1.1, but since updating the panel door to a new design in 2018 to improve quality, insulation & mechanics, there is a need for development of a new Passdoor solution. The purpose of this Master Thesis is to research, develop and present a design for the new Passdoor.

1.2 Scope & goal

The goal of the study presented in this Master Thesis is to research, develop and design a new Passdoor for industrial doors from standard parts developed by ASSA ABLOY. Result of the project aims to be a completion of detailed drawings of the door design, to be ready for production at the manufacturing facility in Holland.

To get a complete understanding of the design and parts, a lot of resources in the project will be put into research, design, computer aided drawing, simulations and calculations to thoroughly examine the functionality, rigidity, manufacturability and insulation properties of the product.

The total scope of this project is limited due to the limitations to the time frame of the Master Thesis. To ensure a result for the Master Thesis, a fallback goal is set together with the main goal. The fallback goal is to finalize a design with computer aided software, without the need for finished detailed drawings of the product.

The total amplitude of testing and prototyping in the project will also be limited by the possibilities given by ASSA ABLOY Entrance Systems.

1.3 Mission statement

Mission statement for the project is developed by the student together with ASSA ABLOY Entrance Systems. This is presented in Table 1.1 below.

Table 1.1 - Mission Statement for the Master Thesis

	Mission Statement: Side Door for Industrial Door
Product description	The side door for an industrial door, as a secondary passage next to the primary gate.
Benefit proposition	Allows passage through the gate, without the need to open the larger, primary gate.
Key business goals	- Allow the option for a side door for customers purchasing the new gate. - Improve the insulation properties compared to the previous side door solution. - Allow for separation between vehicles and people passing through the gate. - Singular and uniform design for Passdoors, independent of dimensions to width, height and thickness.
Primary markets	Customers in need of a secondary Passdoor beside the gate.
Secondary markets	Businesses located in places with extreme temperatures, where insulation is important.
Assumptions & constraints	Limited cost. High manufacturability.
Stakeholders	- Purchasers & users. - Manufacturing operators. - Installation & service personnel. - Distributors & resellers.

1.4 Key people

Listed below in Table 1.2 are the key people who have been involved in the project, except the student himself.

Table 1.2 - Key people involved in the Master Thesis

Name	***Position***	***Role in project***
Anders Löfgren	Senior Mechanical Engineer, ASSA ABLOY Entrance Systems, Landskrona	Supervisor, ASSA ABLOY Entrance Systems
Marcel Ligthart	Senior Mechanical Engineer, ASSA ABLOY Entrance Systems, Holland	Expert on panel gates designed by ASSA ABLOY
Glenn Johansson	Assistant Professor in Product Development	Examinator, Faculty of Engineering at Lund's University
Per Liljeqvist	Lecturer in Product Development	Supervisor, Faculty of Engineering at Lund's University

2 Background

This section provides the reader with background information about the company, the project and the student who completed the project.

2.1 Student background

The responsible student behind this Master Thesis about New Passdoor for Fix Panel Industrial Gates consists of Jonathan Schulz, graduate master student in Mechanical Engineering with Industrial Design at the Faculty of Engineering at Lund's University. Together with the education being angled towards product development, the project has contributed to increased knowledge and skills in both product development on an industrial level, as well as in detailed subjects such as computer aided drawing (CAD), finite element method-simulation (FEM) and other construction methods.

2.2 Company background

ASSA ABLOY Group is a Sweden-based global corporation focused on access solutions, with a background in lock construction. The business was established in 1994, when the Swedish ASSA and the Finish Abloy Oy were merged into ASSA ABLOY. The company extended in 2002 with the addition of the sub-group ASSA ABLOY Entrance Systems when the garage door supplier Besam Sverige AB was acquired. Since then, ASSA ABLOY Entrance Systems has expanded and is now one of the most foremost leaders in door opening solutions across the globe.

In addition to the products offered by ASSA ABLOY Group, being locks, doors and entrance automation solutions, ASSA ABLOY Entrance Systems focuses mainly on industrial grade and high-performance access solutions. This being convenient and secure products, such as residential garage doors, hangar doors, loading dock equipment and industrial gates.

Products offered by ASSA ABLOY Entrance Systems are divided into different departments, which in term is responsible for the respective product area. One of these departments is industrial overhead doors, which is angled towards industrial gate solutions for businesses with warehouses and a need to have easy access for industrial vehicles and deliveries. The Master Thesis will be conducted under this department, focusing on side doors for industrial doors.

2.3 Project background

The focus of this project and Master Thesis was to develop a new Passdoor for one of the industrial doors developed by ASSA ABLOY Entrance Systems. The side door is used to separate humans entering through an industrial gate from vehicles, goods transportation and other things entering through the main entrance gate. This creates a more secure working environment for the people employed in a warehouse environment, as well as increasing insulation properties for the door.

A Passdoor is not a new product offered by ASSA ABLOY Entrance Systems but has been available in different forms for former solutions to industrial doors. However, since the start of a long project with the goal of updating existing industrial doors in 2018 to a modern design with better insulation properties, more variations in size and thickness and for a better price, there is also a need to investigate solutions for a new Passdoor. This new Passdoor has the goal of improving insulation properties and add more size variations for a better cost with fewer parts and a simplified manufacturing process.

3 Theory

The Theory section covers background regarding the product development process, methodologies used to perform the tasks in the project as well as industry standards to take into consideration during the product development process.

3.1 Double-diamond process model

In this section, the theory related to the product development process is discussed based on the methodology derived from the Double Diamond Model of Design. The design process was introduced by the British Design Council in 2005 and defines a system that designers follow during a creative development process.

> *"Start with an idea and through the initial design research, expand the thinking to explore the fundamental issues. Only then is it time to converge upon the real underlying problem. Similarly, use design research tools to explore a wide variety of solutions before converging upon one." (Norman, 2013)*

The Double Diamond process consists of four main stages, as illustrated in Figure 3.1. The concept surrounds the idea to start by exploring the view of possible solutions (divergence) and then taking focused action (convergence) and generating this twice to meet the needs established in the project. The four steps from problem to solution is to discovery, exploration, development & delivery.

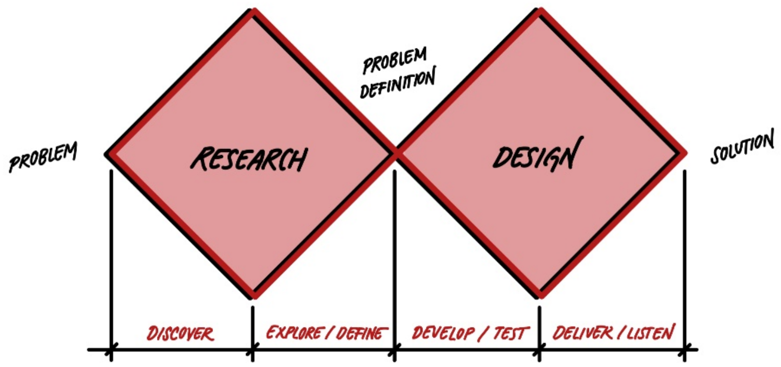

Figure 3.1 - Double diamond process model of product development.

As a starting point, the Double-diamond Process Model of design is not only a process for coming up with an actual end product design. Unlike many other design process methodologies (i.e. Ulrich & Eppinger), the process is also formed to take into consideration that part of the challenge is to actually come to a conclusion regarding what needs to be designed. The first issue is to go from an initial problem and find the right set of needs to fulfill, followed by a definition of what the core-needs and problems in the issue is and what needs to be solved. This can then be passed on to another part of the design process, in which expanding and finding the right solution is the challenge, which is ended by diverging into a final solution.

In the following sections 3.1.1 to 3.1.4, the process of the Double-diamond process model is further, more detailed exploration of the four phases and how they compare to other methodologies (Norman, 2013).

3.1.1 **Discovery**

The Double-diamond process model of design is initiated by an original issue, that needs a solution. This issue is somehow something that needs a solution, which can both be a physical problem related to a product or thing, but just as well a hypothetical problem that needs solving. Instead of going into a solution phase immediately after realizing the problem, the process of the Double-diamond method is entering an initial phase of discovery. The difference between these methods, is that an immediate solution is to converge into a solution, but through discovery the method diverges into a phase of discovering the problem, examining why this is a problem as well as trying to explore how surrounding factors are linked to the problem. The reason for this is to see the bigger picture of the issue and not make the mistake of coming up with a solution that is sub-optimized and creates new issues.

3.1.2 **Exploration**

After discovering of the issue, the related factors and other relevant information, the phase of converging and concretizing the problem is initiated. This is achieved by narrowing down the different alternatives and finding the core problem. This is done by taking everything discovered in the first phase into consideration and scoping down the focus. A successful exploration phase results in a problem definition.

3.1.3 **Development**

Starting from the defined problem definition from the first phase of the Double-diamond process model of design, the second phase is initiated in which the issue is to find the right solution and design things right. This phase consists of extensive concept generation, in which potential solutions to problem is developed. A part of this phase is testing and generating data on performance of the different solutions. What is not part of this phase is decision on what solutions will be used for the final solution. End goal with the development phase is having a plethora of different ways to solve the defined problem.

3.1.4 **Delivery**

The last phase of the Double-diamond process model of design is when a final solution is delivered. Originating from the former development phase, all the defined solutions are presented, examined and rated to make an educated decision on what option is the best one for the problem. Part of this phase is also listening to the different solutions and creating an unbiased opinion on what would work best. The goal with this phase of the entire process is coming up with a final solution.

3.2 The human-centered design process

As an addition to the Double-diamond process model mentioned in section 3.1, the human-centered design process is an iterative method to try out and evaluate ideas during the design process (Norman, 2013).

> *"The Double-diamond describes the two phases of design: finding the right problem and fulfilling human needs. But how are these actually done? This is where the human-centered design process comes into play, it takes place within the double-diamond diverge-converge process" (Norman, 2013)*

The process consists of a circular process, repeating four different activities in the design process. The process fits inside the Double-diamond process model nicely, in which the cycle can be repeated inside all of the four phases, elaborated on in section 3.2.1 to 3.2.5 and shown in Figure 3.2.

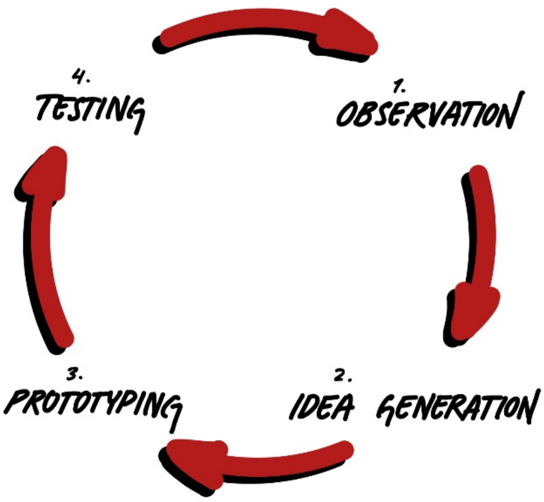

Figure 3.2 – The iterative cycle of human-centered design.

3.2.1 **Observation**

Research is a large part of the design process, which is given time for in the initial stage of the human-centered design process. Making observations can be made both from design research to market research and often results in some kind of design specification.

3.2.2 **Idea generation**

Generating potential solutions or ideation is the part of the human-centered design process that is most creative and develops possible solutions for the problem. Recommendation for this phase is to generate numerous ideas, be create without constraints and to question everything.

3.2.3 **Prototyping**

To reach a conclusion about whether a solution works or not, is to try it. First step towards trying the solution out is to make a prototype, which can be made complicated. Often a low-fidelity prototype might be sufficient to reach a conclusion on whether an idea is good or not.

3.2.4 **Testing**

The last part of the human-centered circle is to try the prototype out, both by oneself but also on a smaller focus-group. Recommendations for testing is to give clear instructions one forehand for the individual

3.2.5 **Iteration**

To enable continuous refinement and enhancement, iteration can make a better result through many cycles of repetition. In the human-centered process the goal is rapid process, which makes it possible to have time for many short iteration cycles. Questioning the result of a cycle, can lead to even better improvements to the end result.

3.3 Industry standards

3.3.1 **EN 13241 - Industrial, commercial and garage doors and gates – Product standard, performance characteristics**

The standard used by ASSA ABLOY Entrance Systems regarding product standard and performance characteristics of industrial, commercial and garage doors and gates, is the standard EN 13241. The standard specifies the safety and performance requirements for these applications, intended for installation in areas in the reach of persons and for which the main intended uses are giving safe access for goods and vehicles accompanied of driven by persons in industrial, commercial or residential premises (Swedish Standards Institute, 2016).

The standard is 40 pages long and many of the relevant points are referred to from the other industrial standard EN 12604. These are listed in previous section. Additional points to the standard relevant to the Master Thesis are presented below.

- All doors, manual and power operated, shall be planned, designed and constructed in accordance with EN 12604 (see section 3.3.2 for further elaboration).
- Resistance of water penetration on the door shall be avoided and it shall be classified in accordance with the water tightness specification classes, specified in standard EN 12425 (see section 3.3.3 for further elaboration).
- To resist the forces from wind loads on the door, it shall be classified in accordance with the wind load classes, specified in standard EN 12424 (see section 3.3.4 for further elaboration).
- Direct airborne sound insulation performance capabilities, when required, shall be determined in accordance with EN ISO 140-3.
- Thermal resistance for a completely assembled door shall be tested or calculated in accordance with standard EN 12428 and annex B.
- Air permeability for a completely assembled door related to overall area and considering the opening joints shall be tested or calculated in accordance with standard EN 12427.
- Where specific product characteristics of thermal insulation, air permeability and resistance to water penetration shall be declared, the design features (including seals, hardware, insulation material, where applicable) shall be included into the durability test in accordance with EN 12605:2000.

3.3.2 **EN 12604 - Industrial, commercial and garage doors and gates – Mechanical aspects – Requirements and test methods**

The standard used by ASSA ABLOY Entrance Systems regarding design and mechanical aspects of industrial, commercial and garage doors and gates, is the standard EN 12604. The standard is 20 pages long, but the relevant parts will be presented below, mentioning safety requirements and protective measures. In addition, the testing procedures to verify the safety measures are presented below as well (Swedish Standards Institute, 2020).

The relevant requirements are stated below.

- The safety factor for materials for calculation purposes is a minimum of 2.0 regarding yield stress. However, for components where testing is performed instead of calculation, the safety factor shall be 1.1 minimum.
- To protect against unintentional and uncontrolled movements, guides and end stops shall be installed into the Passdoor design. Mechanical stoppers in the terminal positions of the door movement shall withstand the energy developed by the possible impact of the door leaf.
- The Passdoor shall incorporate means suitable to prevent movement of the door due to influence of wind at the terminal positions.
- To safeguard against failure of components, the door leaf shall not be able to move uncontrollably if a part fails. In case a hinge breaks or is damaged, an anti-drop safety device shall be able to keep the leaf in position with a maximum displacement of 300mm from the rotation axis. The door shall also be fitted with a protective device to avoid lifting of the door more than 50% of the length of the hinge pin.
- For industrial use the door shall be able to be opened and closed with a maximum force of 260 N, with wind loads and other factors excluded.
- The Passdoor shall be fitted with suitable devices to enable movement, such as handles or pull cords on both sides of the door.
- To protect from pinching of fingers during use, the gaps, other than between the primary and secondary edge in which the distance is reduced during leaf movement, shall be eliminated or safeguarded up to a height of 2.5 m above floor level or other permanent access level.
- Sharp edges shall be eliminated or safeguarded to avoid the risk of cutting when operating the door.
- Passdoors shall be so designed and positioned so that they cannot leave unintentionally their safe position when the main door, in which they are installed, is operated in normal use.
- Parts of doors shall not cause any tripping hazard. Height difference up to 5 mm which occur in the traffic area are not considered dangerous. When the height difference exceeds 5 mm, the raised parts shall be clearly visible themselves or be made so by warning signs, e.g. yellow-black stripes.

The standard also includes how verification of these requirements should take place, stated below.

- To determine correctness of test results, more than one test sample may be used.
- The tests shall be performed at an ambient temperature of (20 ± 10) °C and humidity between 20% and 90%. Other values of temperature and humidity shall be considered if they are declared by the manufacturer.
- The door is to be operated in normal use for 10 cycles. The door shall after this continue to operate without any impairment of safety and operability, such as increased noise levels or friction.
- The verification consists of a test, in which the door shall travel towards an 400x400x400 mm box made out of a hard material (e.g. wood, metal, etc.) with a minimum speed of 0.3 m/s. The door should be able to operate normally after the impact. For this horizontally moving door, the test body is to be put on the floor in the running direction of the main closing edge to the secondary closing edge.
- Door leaf shall travel towards its terminal positions twice with a minimum speed of 0.3 m/s. The door shall be able to operate normally after the impact. Damage to the end stops are controlled.
- To determine unintentional movements due to wind, verification by visual inspection shall be performed as the door is placed in its terminal positions and exposed to the loads.
- To safeguard against dropping of hinged doors, testing is carried out with anti-drop safeguarding installed according to the installation instructions. Faults of hinges or other supporting means are applied one at a time and maximum displacement of the door leaf is measured. When the fault is applied, uncontrolled movement of the door shall be checked.
- To measure forces for operation of the door, place door leaf in it's terminal and middle positions and measure forces required to move it is less than the maximum allowed 260 N.
- When the door is operated check by inspection that the Passdoor is held in the safe position and may not move unintentionally.
- Requirements for thresholds are checked by inspection.
- Protection against sharp edges and drawing points of steel wire ropes, chains and straps shall be inspected.

3.3.3 **EN 12425 - Industrial, commercial and garage doors and gates – Resistance to water penetration - Classification**

The standard used by ASSA ABLOY Entrance Systems regarding resistance to water penetration for doors in a closed position. The doors are intended for installation in areas in reach of people, for which the main intended uses are giving safe access for goods, vehicles, and persons in industrial, commercial or residential premises (Swedish Standards Institute, 2000).

The relevant requirements are:

- A test specimen belongs to a specified classification class when it allows no water penetration under the test conditions. The test pressure is measured in pascal (Pa) and is the differential pressure of one side to the other of the fully closed door. Classes of classification are shown in Table 3.1.

Table 3.1 - Classes of resistance to water penetration.

Class	***Test pressure*** *[Pa]*	***Water spray specification***
0	-	No performance determined
1	30	Water spray for 15 min
2	50	Water spray for 20 min
3	>50	Exceptional; Agreement between manufacturer and purchaser

3.3.4 **EN 12424 - Industrial, commercial and garage doors and gates – Resistance to wind load - Classification**

The standard used by ASSA ABLOY Entrance Systems regarding wind load for doors in a closed position. The doors are intended for installation in areas in reach of people, for which the main intended uses are giving safe access for goods, vehicles and persons in industrial, commercial or residential premises (Swedish Standards Institute, 2000).

The relevant requirements are:

- Wind load is understood as differential pressure of one side of the fully closed door-leaf to the other. A test specimen belongs to a specified class, if the results of a full-scale test, model test, component part test and/or calculations that show that the test specimen can withstand the reference wind load specified for that class.
- Tests or calculations shall also show that the door leaf will remain in position under peak load, 1.25 times greater than the reference wind load unless otherwise required. Permanent deformations or door components are allowed in this case.

Table 3.2 - Wind load classes.

Class	*Reference wind load [Pa]*	*Wind load specification*
0		No performance determined
1	300	
2	450	
3	700	
4	1000	
5	>1000	Exceptional; Agreement between manufacturer and purchaser

- The classes shown in Table 3.2 indicate positive pressure. Suction or reverse loads have to be specified as a negative class i.e. wind load of 300 Pa applied to the inside face of the door is shown as class – 1.

3.4 Method in this project

In a perfect utopian design project, there is a clear and precise template to follow on how to reach the best solution to the problem as possible. Especially in real design processes, there are almost always a need to adjust and adapt the process to solve the problem in question. This results in deviations from the predetermined ways of working, which also must be taken into consideration.

In this Master Thesis, different methodologies have been presented and are intended for use to come up with the best possible solution. Although this is the plan, these plans have been slightly adjusted to fit the project which will be further elaborated on at the end of the project.

3.5 General calculation methodologies

To make competent decisions and correct analyses in the project, it is important to apply correct knowledge about solid mechanics and structure design. Below are some mechanic theories to keep in mind and use while designing and constructing the New Passdoor.

3.5.1 **Statics**

Under equilibrium conditions in a physical system with many different forces in a room with different directions, the sum of all force components will be zero and the moments of all forces combined will be zero, in a static system. (Björk, 2021)

$$\sum F_x = 0 \quad \sum F_y = 0 \quad \sum F_z = 0$$
$$\sum M_x = 0 \quad \sum M_y = 0 \quad \sum M_z = 0$$

Where x, y and z are three against each other perpendicular axes, visualized in Figure 3.3.

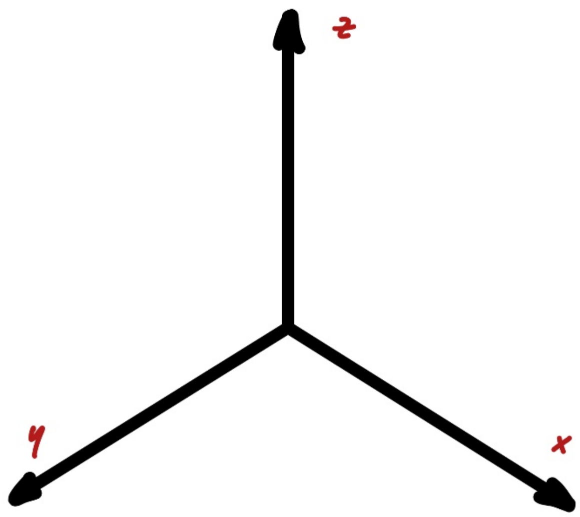

Figure 3.3 - Schematic view of the different axis in a three-dimensional space.

3.5.2 **Twisting and torsion**

Some useful information when designing with stiles and rods is the mechanics of the twisting and torsion of a solid profile. If a stile with the length L is influenced by a turning torque M_v, the ends of the stile will warp in relation to each other by an angle φ (Björk, 2021).

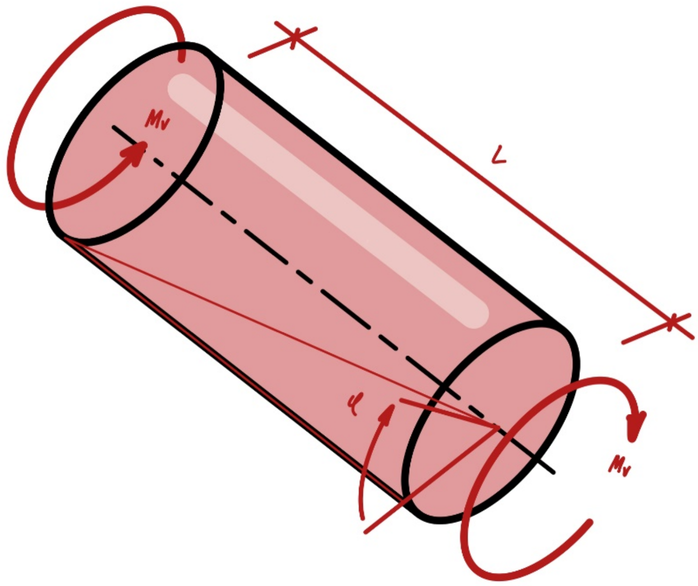

Figure 3.4 - Schematics of angular warping when applying torque to a rod.

The warping angle φ of the two ends is expressed by the relation between G = shear module, I_v = moment of inertia along the rotational axis, M_v = twisting moment and L = length. This is visualized in Figure 3.4 and calculated with help of the equation below.

$$\varphi = \frac{M_v * L}{G * I_v}$$

The material dependent constant G = shear modulus in the formula is calculated through the relationship between the E = elastic modulus and v = Poisson's ratio.

$$G = \frac{E}{2(1 + v)}$$

3.5.3 **Linear interpolation**

In mathematics, a method approximating values on a non-linear curve is linear interpolation. By using data points with known values around an unknown point of interest, an approximate value can be obtained. In Figure 3.5, point (x, y) is the requested point where the value of x is known, but not y.

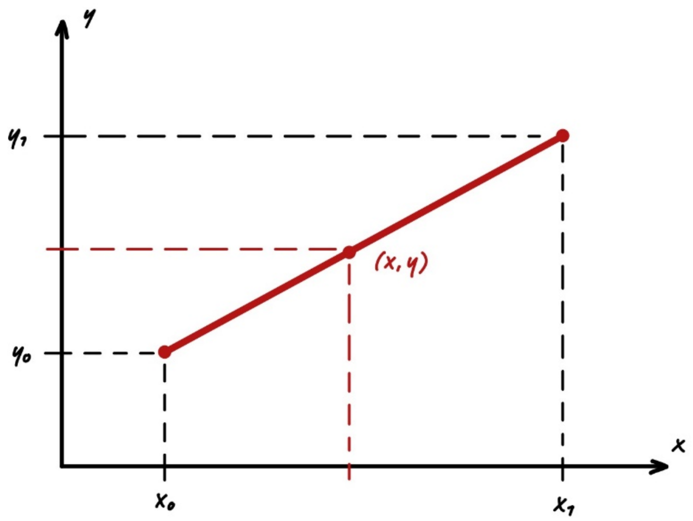

Figure 3.5 - Graphic visualization of the method linear interpolation.

An estimated value of y can be calculated through the equation below, using the method linear interpolation.

$$y = y_0 + \frac{(y_1 - y_0)}{(x_1 - x_0)}(x - x_0)$$

4 Concept generation

The iterative design process with concept generation, testing, and selection are presented in the concept development section.

4.1 Design limitations

Since the New Passdoor targeted to be designed in this Master Thesis is an extension of an existing product, the freedom to make a creative and innovative design job when building the New Passdoor is limited. To fit into the current design for the panel gates, a requirement from the company when designing the New Passdoor is using the same design, aesthetic and parts that the gate itself is modeled from to make it as flush as possible with the rest of the product. This makes the design process less focused on the design of actual components and parts, but more on how to use and configure existing products in ASSA ABLOY's product library to model the New Passdoor. Many of those are used in the current panel gate.

4.1.1 **Variations in height and width**

One of the requirements from ASSA ABLOY Entrance Systems, was to configure the door design to be applicable for many different dimensions, to suit the needs of the customer as well as possible. Other than the thickness of the gate being offered in two different dimensions (42mm & 82mm, where selection depends on need for insulation), the door has to be able to vary in both width and height. Limiting dimensions are retrieved from the previous Passdoor design, which are shown in Table 4.1 and visualized in Figure 4.1.

Table 4.1 - Limiting dimensions for the New Passdoor, based on the old Passdoor.

	Height *[mm]*	***Width*** *[mm]*
min	2076	800
max	2440	1495

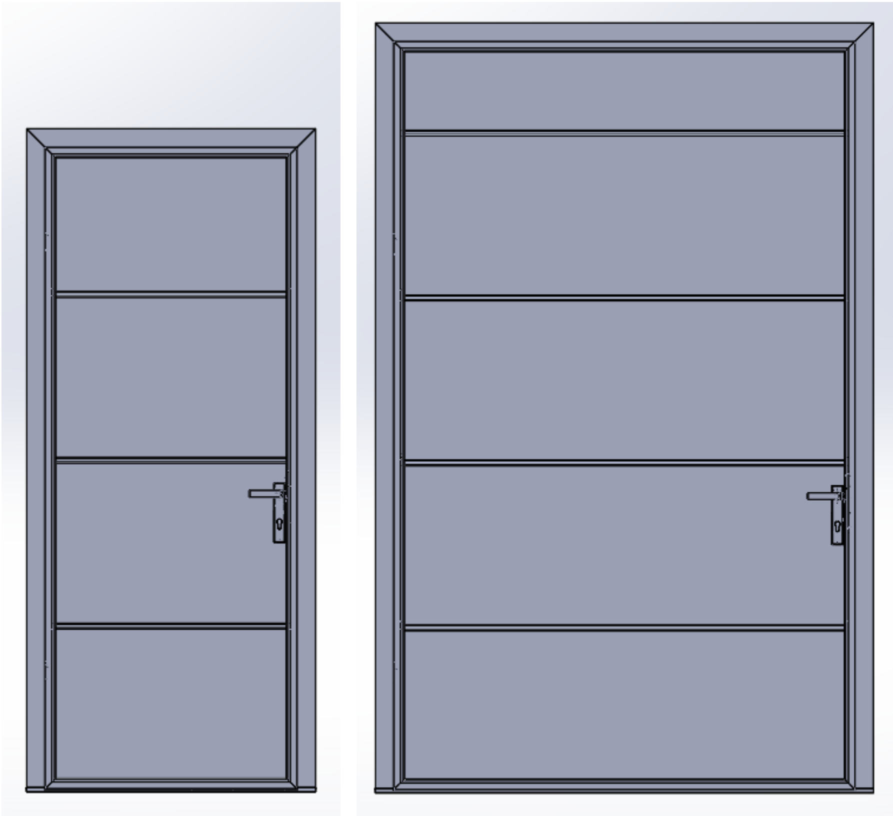

Figure 4.1 - Size comparison between the minimum door size and maximum door size.

4.1.2 **Variations in thickness and broken cold bridge**

Many use-cases of the ASSA ABLOY gates are in environments where effective insulation between outer and inner environment is a crucial feature. The reason for this can be both a challenging outer temperature, or in a use-case where the temperature in the inner hall is carefully monitored. The panels used in the gates are insulated with a filling foam, but to avoid heat transfer through fully metal frame stiles, these are divided between inside and outside, by a plastic middle profile since plastic is considerably less heat conductive than metal. This part blocks heat transfer and the feature is known as a broken cold bridge.

The broken cold bridge feature is part of many of the pieces used in panel gates offered by ASSA ABLOY Entrance Systems and vary in shape and design and are all a standard part bought by the American manufacturer Insulbar®, specialized in insulation equipment and details. What all variations of the broken cold bridge have in common, are how they are mounted. When mounting the piece to the rest of the stile, the aluminum trail in which the plastic piece is placed inside of, is manufactured as an opening, which can be milled together when the plastic piece is placed inside of the trail. This creates a permanent fitting of the cold bridge and is a good seal.

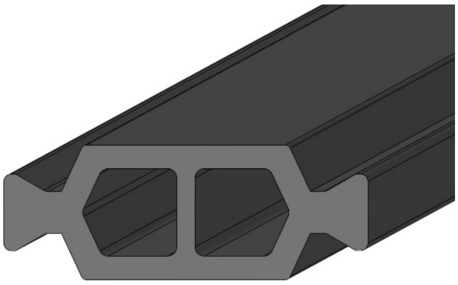

Figure 4.2 - Cross sectional view of the broken cold bridge, standard part to fit the frame stiles of the OH1082P Passdoor.

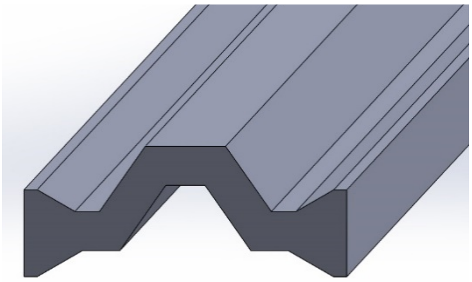

Figure 4.3 - Cross sectional view of the broken cold bridge, standard part to fit the threshold and tube stiles of the OH1082P Passdoor.

Below in Table 4.2, the parts from the ASSA ABLOY panel OH1042P acting as the cold bridge are shown. The cold bridges are also shown above in Figure 4.2 and Figure 4.3. These parts from Insulbar® have been chosen to achieve a configured thickness to fit the 42mm panels. The cold bridge configurations used in some of the OH1042P gate parts are listed below, with article number and thickness information added.

Table 4.2 - Listing of cold bridges by Insulbar used in the OH1042P Passdoor.

	Insulbar Part *[art. No.]*	***Thickness*** *[mm]*
Frame stile	3546	20.0
Tube stile	3388	14.8
Threshold	3388	14.8

4.1.2.1 Broken cold bridge in the 82mm panel gates

The cold bridge used in the OH1042P Passdoor are standard parts manufactured and bought from Insulbar®. The width makes the stile reach the inner thickness of 42 mm, to accommodate the thinner panel. A requirement from ASSA ABLOY Entrance Systems though, is to also create a solution for the OH1082P Passdoor, with the panel thickness increased to 82 mm. To solve this, there are three main design options:

- Extend the metal parts of the stile to +40 mm.
- Extend the cold bridge +40 mm.
- Entirely new design of all parts.

To make an educated decision on what solution to recommend to ASSA ABLOY Entrance Systems, a concept scoring matrix is established, where features are scored with points from 1-5, where a higher number corresponds to well met criteria and lastly weighted to create a balance between different feature criteria. Criteria examined is strength, cost and ease of production. This matrix is shown in Table 4.3.

Table 4.3 - Concept selection matrix for decision on solution for stile design for OH1082P.

		EXTENDED METAL		***EXTENDED COLD BRIDGE***		***NEW DESIGN***	
parameters	***weight***	***rating***	***weighted***	***rating***	***weighted***	***rating***	***weighted***
strength	*40%*	*4*	*1.6*	*2*	*0.8*	*5*	*2.0*
cost	*30%*	*2*	*0.6*	*4*	*1.2*	*1*	*0.3*
production	*30%*	*2*	*0.6*	*4*	*1.2*	*1*	*0.3*
SUM			***= 2.8***		***= 3.2***		***= 2.6***

The matrix shows that the best choice for stile design is to extend the thickness through changing to a longer broken cold bridge. However, there currently are no available cold bridges from Insulbar® with the desired increased dimensions. For example, the part needed for the frame stile of the OH1042P Passdoor must be 60 mm wide, but the widest configuration offered by Insulbar® is the 2636 profile, with a thickness of 41 mm. The widest cold bridge in total is Insulbar® 3339 with a width of 54 mm (Insulbar, 2020), featuring a slightly modified side profile design not perfectly fitted for the use in the frame stiles of the new Passdoor in addition to being 6 mm short. Visual representations of the desired cold bridge-designs for the OH1082P Passdoor are shown below in Figure 4.4 and Figure 4.5.

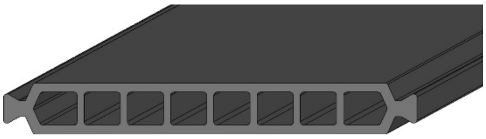

Figure 4.4 - Cross sectional view of the broken cold bridge, specially designed with dimensions to fit the frame stiles of the OH1082P Passdoor.

Figure 4.5 - Cross sectional view of the broken cold bridge, specially designed with dimensions to fit the threshold and tube stiles of the OH1082P Passdoor.

To produce these new parts, new tooling for manufacturing of new elongated versions of the cold bridges is needed. This may result in a price increase on the OH1082P Passdoor, to finance the new tooling needed. Additionally, another large concern regarding the extended cold bridges is the potential decrease in stability due to the extended use of softer plastic. This might affect the stability and torsional rigidity of the door, which is further examined in section 4.3.1.1, regarding mechanical testing.

4.2 Component selection

The basic components to model a door are the door itself, a frame to put it in and a set of hinges to connect them to each other. This can after this be further deconstructed into smaller, more detailed components, which in this Master Thesis is based on the overall design and construction language of existing industrial gates.

All components are modifications of existing products in the ASSA ABLOY product library and retrieved through the company's digital file management center.

4.2.1 **Panels**

To maintain the design language of the rest of the industrial panel gates and to make the addition of a Passdoor as flush to the overall gate design as possible, a requirement from ASSA ABLOY Entrance Systems was to construct the door leaf out of the same panels that the gate itself is constructed from. To create a uniform design, the panels inside the door should be vertically lined up with the panels of the gate. In Figure 4.6 a visual representation of this matching of pattern is shown.

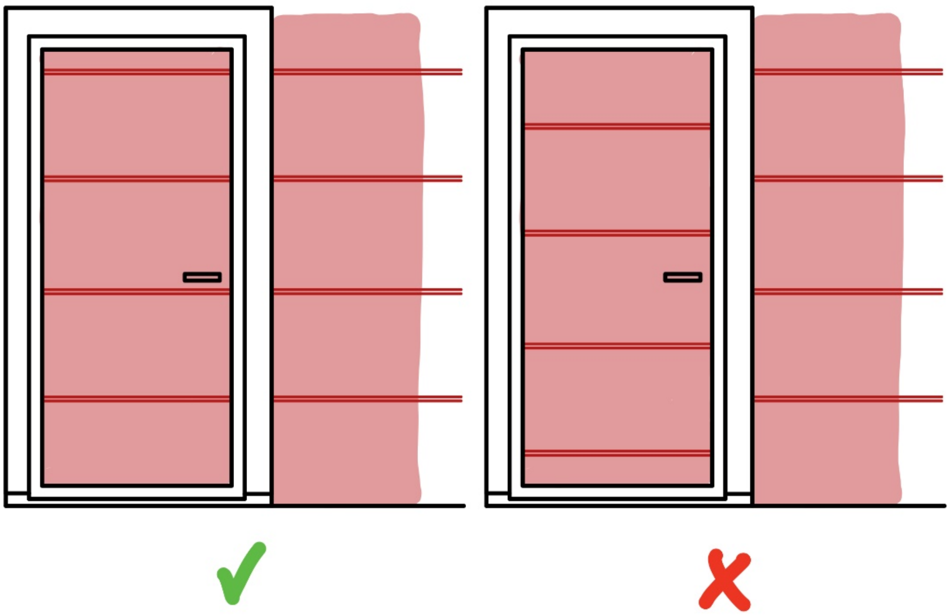

Figure 4.6 - Desirable and undesirable placement of the panels for the door in relation to the primary gate, to maintain a uniform design language.

The panels used are insulated industrial gate panels in the two gate thickness configurations, 42mm and 82mm. The panels are constructed out of cold pressed sheets of stainless-steel metal, with an inside filled up with insulating PUR plastic foam. The 42mm thick panel is also available with metal sheets out of aluminum, but this configuration will not be included in the analysis in this master thesis.

Additional metal details for reinforcement are also part of the design, as well as sealings in an EPDM silicone material. The panels are unique in terms of a cross-sectional shape that allows for folding of the panels when they are stacked on top of each other. This is achieved through a shark-fin-like design, shown in Figure 4.7. This feature is not important in this Master Thesis though, since the door is placed in a fixed section and will not be designed with a folding functionality but with a vertically fixed shape. In the door, panels will merely be stacked horizontally on top of each other.

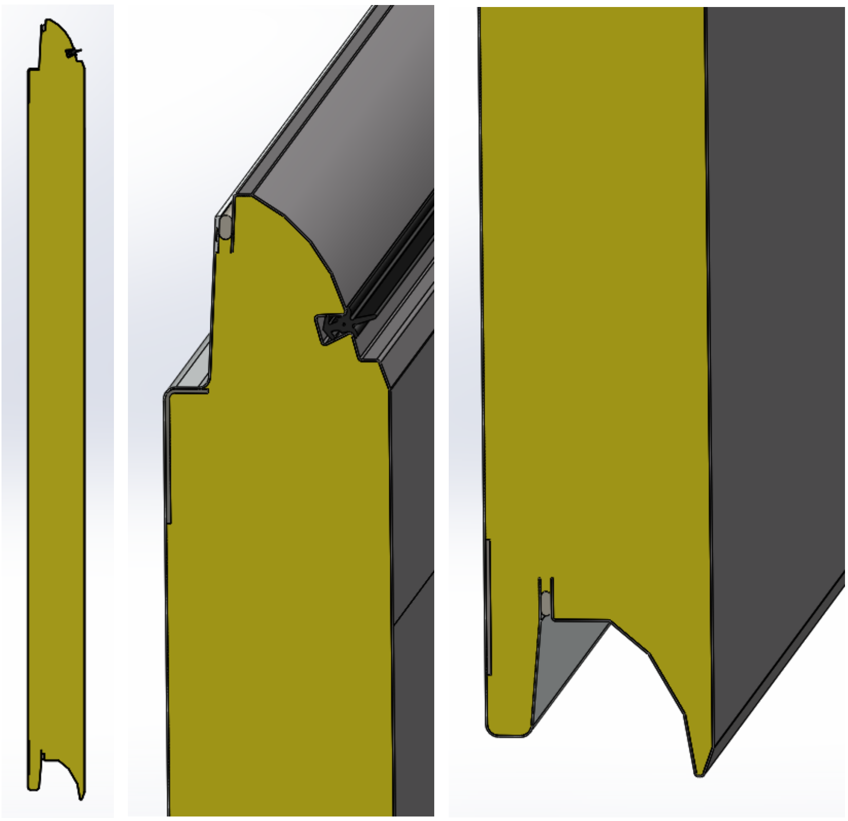

Figure 4.7 - Cross-sectional shape of the OH1042P panels, where the yellow filling foam is encapsulated by two metal sheets, along with detail parts such as reinforcements and seals.

The panels are ordered in 12-meter-long pieces each from the manufacturer and are then cut into smaller pieces easily with a larger autonomous sawmill. This makes the process of producing doors ordered with custom dimensions simple, as the only processing needed for most of the panels used are just these vertical cuts. Additionally, only the bottom and top panel must be cut longitudinally as well, to fit the pattern of the rest of the panels on the side in the gate, as well as being adjusted to the custom height of the door. Depending on the selected door height, either four or five panels will be stacked on top of each other to fill up the door frame, reaching five panels if the height exceeds 2 144 mm. The panel is available in the two thicknesses 42mm and 82mm and both sizes benefit from the same manufacturing process.

Density of the panels vary, depending on what thickness is selected for the door. Naturally due to the combination of materials in the part, the weight is not evenly distributed, but can be approximated as being linearly related to the surface area of the door. For the 42mm option of the door, the surface density for the panels is 13 kg/m^2 and for the 82mm option 15 kg/m^2.

The panels used in the Master Thesis are retrieved from ASSA ABLOY's file management center with the drawing numbers shown in Table 4.4. The CAD file is a SolidWorks assembly, but only the top files used are mentioned in this report.

Table 4.4 - Specifications of what parts are used for the panels in the New PSD.

	Passdoor for OH1042P	*Passdoor for OH1082P*
Panel	D001020762-001	D001020930-001

4.2.2 **Frame stiles**

The structural backbone of the whole industrial gate are the frame stiles, out of which the functional parts in both the outer and inner door frame are built up from. These are designed to hold the whole structure together and through being designed in such a way that makes it possible to fit in the panels into the trail built up by the edges of one side of the stile, the panels can be neatly stacked on top of each other inside the inner door frame. The design of the frame stile is shown in Figure 4.8.

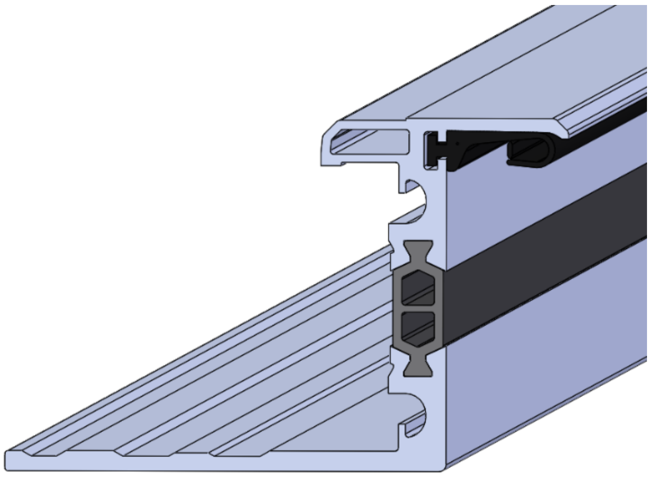

Figure 4.8 - Cross-sectional view of the 42mm frame stile, with the broken cold-bridge apparent by the dark grey piece of plastic between the metal sub-stiles. The opening on the left side of the profile marks out where the panel can be fitted inside the frame of the door.

The stile itself is created out of two profiles of extruded aluminum, with the plastic cold bridge fitted in between. An additional softer rubber EPDM seal is also added on the opposite side of the frame stile as the panel, as a separate part before the part is processed. This seal will be compressed of another frame stile when the door is closed, creating a double seal around the door that insulated the structure well.

Adjustment of the frame stiles from adapted for a 42 mm panel to an 82 mm panel means extension of the plastic cold bridge, decided on in section 0. The OH1042P cold bridge is 20 mm wide, and henceforth the OH1082P cold bridge needs to have a width of 60 mm. A cold bridge this wide is not currently available by Insulbar® and therefore, detailed drawings of this custom part is included in Appendix D, with a picture of the frame stile with the extended cold bridge shown in Figure 4.9. A concern regarding this OH1082P frame stile with the extended broken cold bridge, is the strength and solidity of the part, due to the extension of the softer piece of the stile. Especially torsional rigidity is a greater concern in the new OH1082P frame stile as the weight of the Passdoor might result in twisting of the frame stile. This issue is further explored in section 4.3.1.1, to evaluate strength and discuss suggestion for further reinforcement.

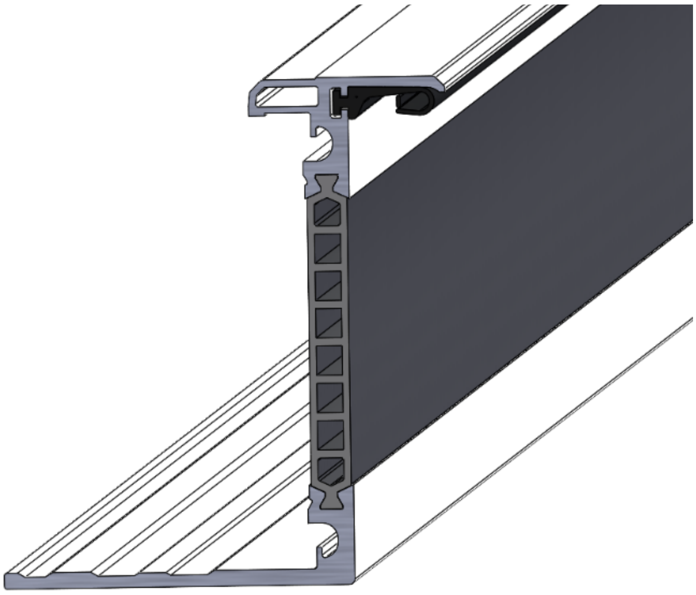

Figure 4.9 – Frame stile for the OH1082P door with a modified cold bridge.

The stiles are ordered in 5-meter pieces and are cut into shorter parts with lengths adjusted in accordance with the desired door dimensions. The manufacturing required for making the inner and outer frame parts after this is elaborated on in section 4.2.7 regarding assembly of the Passdoor and in the detailed drawings in Appendix D.

The frame stiles used in the Master Thesis are retrieved from ASSA ABLOY's file management center, or created with inspiration from these, with the drawing numbers shown in Table 4.5. The CAD file is a SolidWorks assembly, but only the top files used are mentioned in this report.

Table 4.5 - Specifications of what parts are used for the frame stiles in the New PSD.

	Passdoor for OH1042P	*Passdoor for OH1082P*
Open stile	D001037636-001	D001037636-MOD82
Seal	D001041232-001	D001041232-001

4.2.3 **Tube stiles**

The tube stiles are an additional attachment to the outer frame stiles in the New Passdoor. The addition of this part has a very functional approach and has three main functions – increasing stability to the outer door frame, acting as a mounting piece to the outer frame stiles and lastly bridging the gap between the surrounding environment and the New Passdoor.

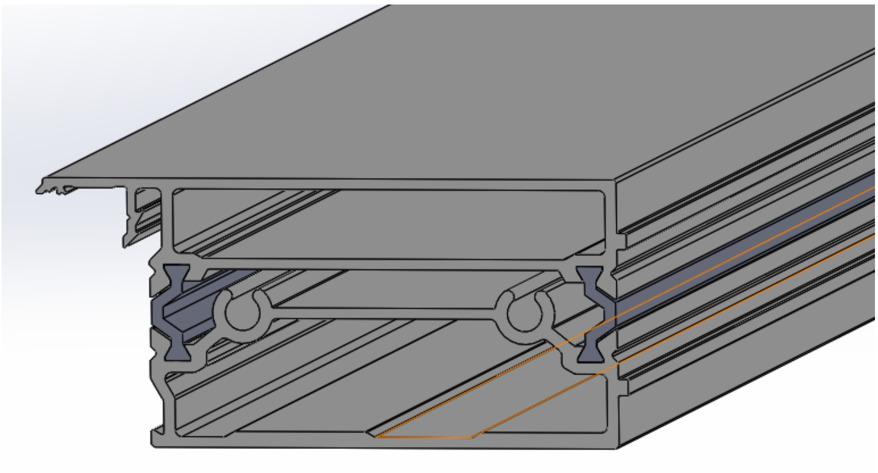

Figure 4.10 - Cross-sectional view of the OH1042P tube stile, with the two broken cold-bridges apparent by the blue pieces of plastic between the metal sub-stiles. The right-hand side is where the tube stile is attached to the frame stile and the opposite is to the surroundings.

Compared to the frame stile, the rectangular shape of the tube stile with lots of inner reinforcements results in a very stable structure. As the weight of the door blade in the New Passdoor puts a lot of load and stress on the hinge side of the outer frame of the door, the addition of this stiff piece brings a more solid and confident rigidity for the outer frame structure. Less risk for deformation in the outer frame means lower risk for hanging of the door or other sturdiness issues. A potential negative with this addition is the heavily increased weight of the New Passdoor. This can be disregarded though since the outer frame is a fixed part where heaviness is nothing but a welcome addition for stability.

In addition to the increased stability of the door, the tube stile does also bridge the gap between the New Passdoor and the surrounding structure. As seen on the left side in Figure 4.10, the metal extrusion features a lip with a 90° angle which is meant as a mounting point for a surrounding wall, column, or other permanent structure. By fixing the lip by screws or bolts to the wall, the gap between wall and stile can be filled up with insulating foam to achieve a well-insulated attachment of the door.

The tube stile is also fixed to the bottom threshold by screws into the holes seen in the cross section and to the frame stiles by pop rivets. More about these assembly features in section 4.2.7. A cross-sectional view of the frame stile together with the tube stile is featured in Figure 4.11.

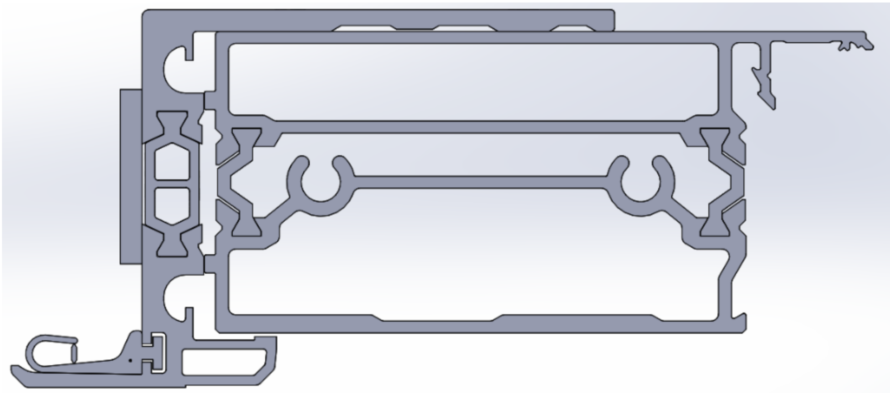

Figure 4.11 - Cross sectional view of the frame stile and tube stile mounted together.

The broken cold bridge featured in the OH1042P version of the door consists of two mirrored parts with the width 14.8 mm, as mentioned in section 4.1.2 about the broken cold bridges. Thus, the version of the tube stile needed for the OH1082P door requires a 54.8 mm cold bridge, but Insulbar® does not offer a piece with these dimensions as a standard component. Therefore, detailed drawings of this piece are included in Appendix D.

The tube stiles used in the Master Thesis are retrieved from ASSA ABLOY's file management center, or created with inspiration from these, with the drawing numbers shown in Table 4.6. The CAD file is a SolidWorks assembly, but only the top files used are mentioned in this report.

Table 4.6 - Specifications of what parts are used for the frame stiles in the New PSD.

	Passdoor for OH1042P	*Passdoor for OH1082P*
Open stile	D001079847-001	D001079847-MOD82

4.2.4 **Threshold**

Because the outer frame of the New PSD will be placed on top of the ground, a floor, or another planar surface, it was decided that a dedicated threshold will be used instead of a normal frame or tube stile. Instead of the stiles being mounted 90° to another stile with the 45° chamfer, the stiles are just cut flat and placed on top of the threshold, which makes the manufacturing process easier. They are then mounted by a c-mount inside of the tube stiles, more about this mentioned in section 4.2 regarding assembly features.

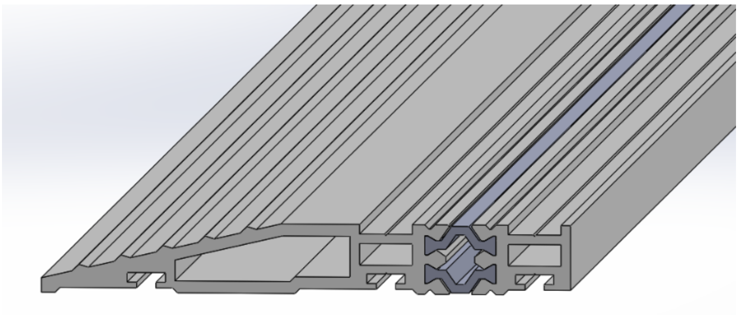

Figure 4.12 - Cross-sectional view of the bottom threshold, with the broken cold-bridge shown in blue.

There are many different types of thresholds in the ASSA ABLOY product library, with varying heights and thicknesses depending on usage. Examples of variations in threshold design is shown in Figure 4.13. The discussion about what threshold to use was held but resulted in choosing the lowest threshold available, according to the standard EN 12604, presented in section 3.3.2. This to avoid risk for tripping, since the New Passdoor is supposed to be used mainly for pedestrian traffic, but also increase aesthetic appearance. According to the standard, since the threshold chosen gives a height difference of over 5 mm, it needs to be clearly visible by warning signs or a bright color, which must be taken care of when mounting the threshold by for example painting the raised side or covering it with bright tape.

The threshold selected is shown in Figure 4.12 and is also available with seals along the underside of the profile, that can be inserted into tracks on the bottom of the component. The seals are made from EPDM rubber and each threshold have room for attachment of three parallel seals for maximum insulation and wind blocking. Seals are mounted separately but recommended to be added before processing of the threshold to ensure simple and clean manufacturing of the details with clean and accurate cuts.

Figure 4.13 - Other variations of thresholds in ASSA ABLOY Entrance Systems doors for industrial use, not selected for use in the new Passdoor.

The selection of a threshold instead of a stile like in the other structural parts of the New Passdoor, increases cost since it is a whole new part that needs to be manufactured. This cost-increase was decided to be worth it though since it accelerated usability, appearance and lets the door follow the established standards.

The thresholds used in the Master Thesis are retrieved from ASSA ABLOY's file management center, or created with inspiration from these, with the drawing numbers shown in Table 4.7. The CAD file is a SolidWorks assembly, but only the top files used are mentioned in this report.

Table 4.7 - Specifications of what parts are used for the threshold in the New PSD.

	Passdoor for OH1042P	***Passdoor for OH1082P***
Threshold	D001075760-001	D001075760-MOD82
Seal	D001020704-001	D001020704-001

4.2.5 **Hinges**

The hinge is an essential part that connects the outer frame to the inner frame in the New Passdoor. Apart from being responsible for the functionality of the door, in terms of being the movable part that accommodates opening and closing, it is also one of the parts that is exposed to the largest loads, stresses and strains. In order not to suffer from fatigue or break at excessive loads, a hinge that is stable and can withstand multiple cycles of opening, closing and tough handling is required.

As ASSA ABLOY is a company that produces opening solutions, there naturally are many available hinges to choose from in the product library. For the New Passdoor, a rough selection gives three possible types of hinges to be used in the door. They are a roton hinge, a hinge inside the PSD profile and a hinge on the outside of the door leaf.

4.2.5.1 Roton hinge

The roton hinges are several ASSA ABLOY patented designs, which do not feature a specific hinge part, but has the common denominator that they feature a hinge mechanism incorporated directly into the extruded frame stiles. This design is featured in many of the profiles offered by ASSA ABLOY and follows the whole height of the door. It is shown in Figure 4.14.

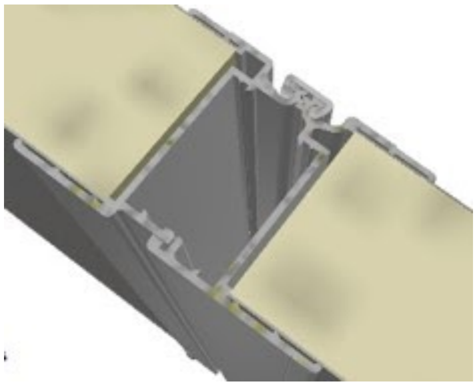

Figure 4.14 – Design of a roton hinge offered by ASSA ABLOY.

The positive sides of using these types of hinges are mainly the cost efficiency, since skipping an entire part in the door assembly shaves cost considerably in both assembly and bill of materials. In production the hinge is also easy to mount, it gives a smooth and symmetrical outlook and has the possibility to be opened 180° under the right circumstances.

The negative sides of using these types of hinges are mainly that it gives the Passdoor a very weak point, where wind and weight loads can lead to flanges on the outside of the door frame. In testing made by ASSA ABLOY in 2018, when using this design on a OH1042P Passdoor it is by far the weakest point compared to everywhere else in the assembled Passdoor. In addition, the hinge is not service friendly, has no possibility to be corrected or aligned after installation and has the need for a whole different frame profile on only one side of the door. Dirt getting into the roton hinge is also hard to remove, destroys the door and makes it not function properly. The hinge also causes corner problems in the door, where the hinge does not match up with the rest of the Passdoor design. Some of these cases are shown in Figure 4.15.

Figure 4.15 - Corner problems with the roton profile used in Passdoors.

4.2.5.2 Hidden hinge

The hidden hinge is an ASSA ABLOY design in which the housing of the hinge is hidden in between the outer and inner frame stile. The mounting plates of the hinge are also designed to fit inside of the gap between outer and inner door frame, which makes the hinge invisible from the outside, but gives a small distance of encapsulated air between the frame stiles, improving insulation properties. The hidden hinge is shown in Figure 4.16.

Figure 4.16 - Look of the hidden hinge seen from the space between inner and outer Passdoor frame.

The positive side of using a hidden hinge in the New Passdoor is that the hinge has good resistance to forces coming from wind and weight, which is positive when being used in industrial environments where the loads and amount of use cycles of the door might be extreme. The hinge is also service friendly and gives the possibility to be adjusted after installation. In addition, the hidden hinge fulfills the standard EN 12604, presented in section 3.3.2, since it limits lifting of the door and does not let the door unintentionally leave its safe positions. The hinge also gives the door a smooth and symmetrical look, as it is invisible when the Passdoor is closed.

The negative side of using a hidden hinge is the higher price compared to other competitors and a tighter opening angle of just 100° compared to 180°. Due to play in hinge, it also suffers from higher risk of hanging loose or getting crooked, and the metal build also connects both metal sides of the stile, forcing a risk on the plastic cold bridge in the door. The cuts needed in the frame stiles also create a risk for potential stability decrease of the structure.

4.2.5.3 External hinge

An external hinge is a very normal and simple solution to a hinge and is positioned on one side of the gate. There are many external hinge solutions offered by ASSA ABLOY, out of which one example is shown in Figure 4.17.

The positive side of using an external hinge is that the hinge is easy to install, as it can be fastened in the PSD profiles on the outside and it can be used on many types of stiles as it is easily attachable without much preparation other than drilling. Additionally, the door is made more service friendly using the external hinges.

Figure 4.17 - Two types of external hinges offered by ASSA ABLOY.

The negative side of using the external hinge is that it is priced higher than many other hinge types and is only mountable from one side, which is an issue from a production standpoint as the door has to be flipped over for installation of the hinge. Aesthetically, the hinges are also very visible and protrude from the door and the loads from weight and wind are led to the outside of the door leaf, which is more prone to warping deformation than the inside of the stile.

4.2.5.4 Selection of hinge type

For the New Passdoor, one type of hinge out of the three options listed above is to be chosen for implementation to the design. To make an educated choice between the three alternatives, a concept scoring matrix is set up, in which each of the three hinge types are scored from in five different categories. The scoring varies from 1 to 5, where a low number signals a low score in the specific category and a high number equals well-met requirements.

The parameters in which the options are scored are the following:

- **Strength** – measures how much load the hinge is rated for in the relevant directions and how well it withstands deformation and hanging of the door.
- **Unit cost** – cost for the hinge part together with manufacturing cost for mounting.
- **Production** – how simple the door is to manufacture when using the hinge in question.
- **Service** – reparability and ease of accessing the hinge after installation.
- **Outlook** – aesthetic appearance and intrusiveness of the hinge placement design.

Below in Table 4.8, the different parameters are scored and weighed against each other to evaluate which one is the best choice to use in the New PSD.

Table 4.8 - Selection of hinge type.

		ROTON HINGE		***HIDDEN HINGE***		***EXTERNAL HINGE***	
parameters	***weight***	***rating***	***weighted***	***rating***	***weighted***	***rating***	***weighted***
strength	*25%*	*2*	*0.5*	*4*	*1.0*	*4*	*1.0*
unit cost	*20%*	*4*	*0.8*	*2*	*0.4*	*3*	*0.6*
production	*15%*	*3*	*0.45*	*3*	*0.45*	*3*	*0.45*
service	*25%*	*1*	*0.25*	*4*	*1.0*	*3*	*0.75*
outlook	*15%*	*2*	*0.3*	*5*	*0.75*	*1*	*0.15*
SUM			***= 2.3***		***= 3.6***		***= 2.95***

Result from the concept scoring matrix shows that the Hidden Hinge is the best selection for the new Passdoor, which is why this option is selected for further development.

The data and CAD models of the hinges used in the Master Thesis are retrieved from ASSA ABLOY's digital file management center with the drawing numbers shown in Table 4.9. However, the appropriate number of hinges used in the door is yet to be determined, see section 4.3 for mechanical testing and evaluation of the component. The CAD file is a SolidWorks assembly, but only the top file used is mentioned in this report. An advantage coming with choosing the hidden hinge, is that the same hinge can be used for both OH1042P and OH1082P Passdoors.

Table 4.9 - Specifications of what hinges are used in the New PSD.

	Passdoor for OH1042P	***Passdoor for OH1082P***
Hinge	D001059280-001	D001059280-001

4.2.6 **Handle, lock box & lock plate**

To construct a functional door, a mechanism for keeping it shut after being closed is required. This functionality can be achieved in a lot of ways and the specific method is in essence not important to the actual door design itself for the project to be successful. However, some sort of locking mechanism is nonetheless required to result in a functional door and in order to fulfill the standards mentioned in section 3.3. The chosen handle, lock box and lock plate are shown in Figure 4.18, note that the same parts can be used in both the OH1042P and OH1082P Passdoor.

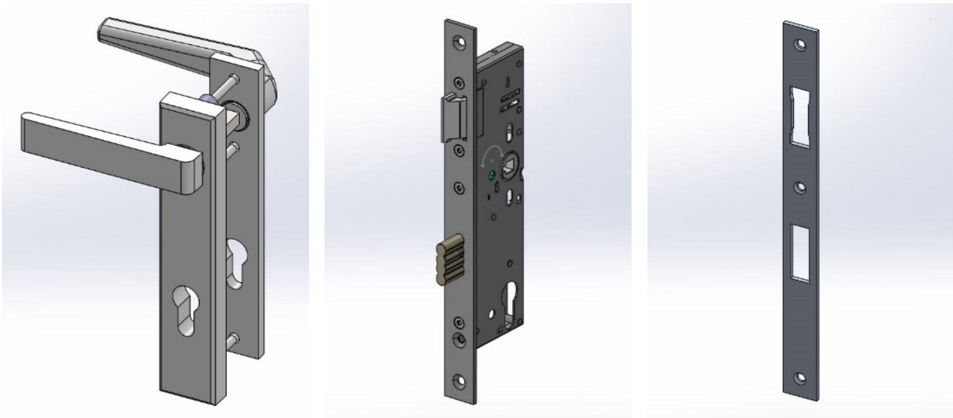

Figure 4.18 - Selected handle, lock box and lock plate for the new Passdoor.

The handles, lock box and lock plate used in the Master Thesis are retrieved from ASSA ABLOY's file management center, or created with inspiration from these, with the drawing numbers shown in Table 4.10. The CAD file is a SolidWorks assembly, but only the top files used are mentioned in this report.

Table 4.10 - Specifications of what hinges are used in the New PSD.

	Passdoor for OH1042P	*Passdoor for OH1082P*
Handles	D001097212-001	D001097212-001
Lock box	D001093794-001	D001093794-001
Lock plate	D001093793-001	D001093793-001

4.2.7 **Assembly features**

Although all the parts of the New Passdoor have been decided on in the sections above, there is a need to clarify ways in which the different parts should be mounted together into a finished product along with parts needed for assembly such as screws, bolts, rivets and more. The process of completing this list of assembly features varies in simplicity between different parts – some parts used have pre-decided mounting solutions and others need custom solutions for mounting. Below, these are listed in section 4.2.7.1 to 4.2.7.6.

4.2.7.1 Inner frame stile corners

In former versions of the fix panel Passdoor from ASSA ABLOY Entrance Systems, a proven solution for mounting the frame stiles together is to mount them together with the gate panels acting as a mounting bridge. By making double sets of holes in the corners of all pieces cut into a 45° angle, these holes can be used for attachment of the frame stiles directly onto the panels and fix the frame stiles to each other simultaneously. This is shown in Figure 4.19. The holes into the frame stiles are inspired by an ASSA ABLOY drawing design, D001082301-001, but inverted and adapted for the inside profile. The modified drawing for holes in the inner frame stiles can be seen in Appendix D, called NEWPSD42-DET07 and NEWPSD82-DET07.

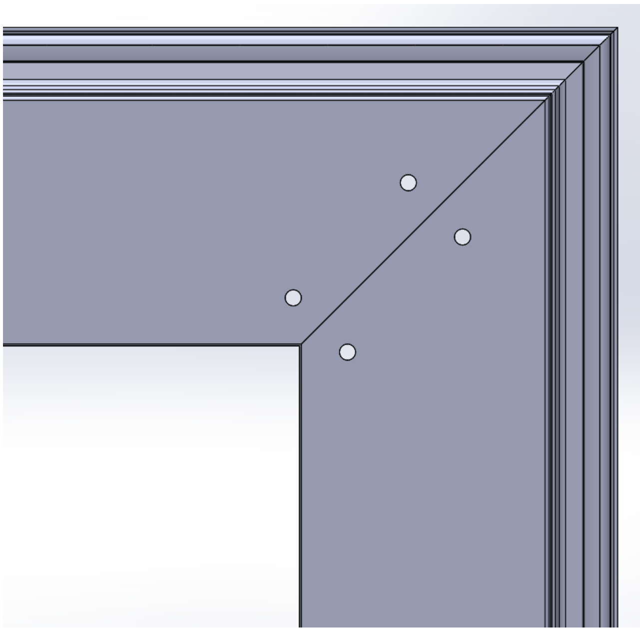

Figure 4.19 - Placement of the mounting holes on the inside of the inner frame.

The recommended method for attaching the frame stiles to the panels used by ASSA ABLOY Entrance Systems, is presented shortly below:

- Fix the panel and two frames together into the desired shape, suggestibly in a fixture.
- Pre-drill the four holes into the (only through the metal sheet, avoid drilling too deep into the foam) with a 4.2 mm drill.
- Use a pop rivet to fix the frame stiles permanently to the panels.

Note that it is recommended that the bottom panel and corners are mounted together first and that all panels are stacked into the inner frame, before holes in the top panel are drilled, to secure the right fit and avoid bad fitting due to tolerance miscalculations.

Apart from the larger components that are mounted together in this operation, the smaller details that are required for the mount are pop rivets are listed in Table 4.11 below.

Table 4.11 - Components required to mount inner frame stiles to each other.

Component	*Parts per mounting point*	*Mounting points*	*Total No. of parts*
Pop rivet 4mm	4	x 4	= 16

Also note that this is an approved method by ASSA ABLOY Entrance Systems, but looking forward, more durable and better solutions can be developed in the future. For instance, the fact that the pop rivets only attach the frame stiles to one side of the panels, result in that potential deformations can make the frame stiles misalign on the opposite side of the pop rivets. This is not desired and could for example be cured through placement of a similar hole on the other side of the frame stile for a pop rivet mount there as well.

An early idea that was explored loosely in the beginning of the project was to create a new part, shaped like a bracket with a 90° angle that could be inserted into the frame stile and drilled into place from the side of the stile to minimize impact of the appearance of the door. This part could also be used for the outer frame stiles, which makes the design efficient since it can be used in six places in a single Passdoor (four corners in the inner frame and two in the outer frame). This idea can be further explored in a future project at ASSA ABLOY Entrance Systems.

4.2.7.2 Panels to inner frame

As mentioned in section 4.2.2 about the frame stiles, an efficient part of the design is that these stiles feature a built-in track, in which the gate panels can be placed within, shown in Figure 4.20. When closed together by the four stiles in a rectangular frame, the panels are locked in place and cannot be removed without disassembly of the whole frame section.

This results in a non-necessity of mounting parts for the panels to the inner frame, since the top and bottom panel are already fixed into place through the method mentioned in the section 4.2.7.1 above about inner frame stile corners.

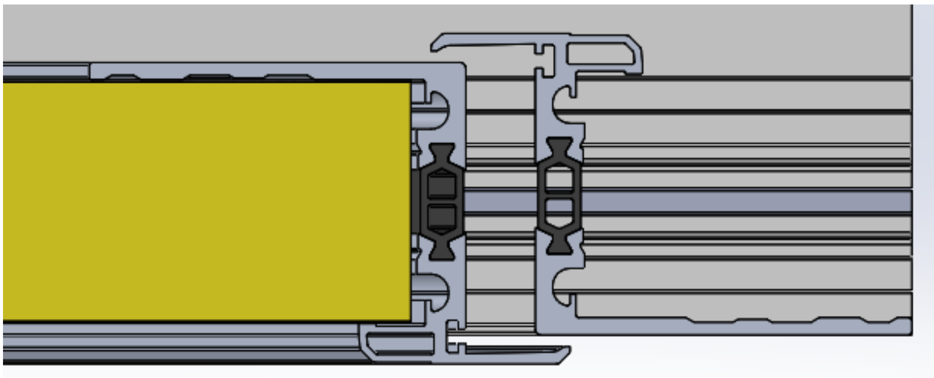

Figure 4.20 - Placement of the panel (yellow) inside of the frame stile (grey) with a tight fit to ensure that it does not move when operating the door.

Additionally, if a new method for attaching the frame stile profiles to each other without fixing the bottom and top profile to the frame, there still is no need for attaching or fixing the panels with screws into the frame stile if the parts are manufactured with tight tolerances. This effective dodging of extra assembly parts results in a more compelling cost for manufacturing of the door.

4.2.7.3 Outer frame stile to outer tube stile

To ensure a stable construction and that the door does not deform or start hanging, it is of utmost importance that the outer frame stiles are well mounted. To achieve this, mounting of the frame stiles in the most stable part of the New Passdoor construction is a good start, which is the tube stiles, attached to the surrounding structure.

The tube stile can have many different looks, but what the different configurations have in common is that all outer frame stiles can be attached to one. Since the frame stiles are already fixed to the tube stile in the door opening direction, due to the slot for the tube stile integrated into the profile, the door only needs to be fixed in a vertical and horizontal direction. This is best done with pop rivets and by using the same as for attachment of the inner frame stiles to the panels, the cost of this attachment can be minimized.

A recommendation for this attachment of the outer frame stiles to the tube stiles, is to place the rivets mostly clustered towards the end of each stile component. Having two pop rivets in each end of the stiles ensures that the whole structure is held together. This design is clarified in drawing NEWPSD-DET01 in Appendix D. To further reinforce the attachment of the frame stiles to the tube stiles, several pop rivets can be placed along the sides of the frame stiles, spaced evenly, to avoid deformation of the frame stiles when exposed to greater loads such as from the hinges. As the hinges are where the force from the door's weight is located, reinforcement by pop rivets at these locations are a suggestion for improvement. Adding complementary pop rivets at the top of the outer frame is also a good way to secure the stability of the structure. Additionally, placing the pop rivets evenly spaced on the outer frame is recommended to improve appearance. Specification of components needed for assembly is shown in Table 4.12.

Table 4.12 - Components required to mount outer frame stiles to the tube stiles.

Component	*Parts per mounting point*	*Mounting points*	*Total No. of parts*
Pop rivet 4mm	8 // 6	x 2 // x1	= 22

4.2.7.4 Outer tube stile to threshold

Attachment of the threshold to the tube stiles in the New Passdoor, is a crucial part of the new Passdoor. Since the tube stiles offer rigid attachment to the rest of the building or structure the Passdoor and gate is installed in, while the threshold is a component that needs to withstand a lot of load from daily use of the Passdoor. Every time a person passes through the door or something is rolled through the opening, large forces will be placed at the threshold, which creates a need for a fix construction.

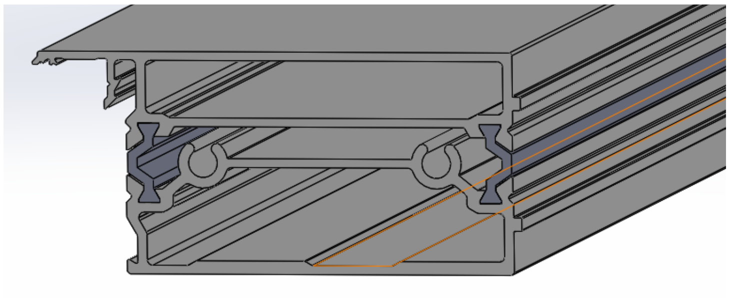

Figure 4.21 - Cross-sectional view of the tube stile, showing the screw locations directly integrated to the metal profile.

To deal with this, a well-designed part of the tube stiles in the New Passdoor, is the incorporation of screw holes directly into one of the aluminum profiles. These screw holes are directed along the stile's direction of propagation, which is also perpendicular to the thresholds horizontal plane. This is shown in Figure 4.21. By simply drilling holes with the right dimension through the threshold that match the hole positions in the tube stile, the threshold can be easily fixed to the rest of the Passdoor structure.

An important detail to note is that the screw holes need to be recessed into the threshold profile, as the bottom of the threshold is placed directly onto the ground and does not allow for any space for a protruding screw head. Additionally, the threshold needs to be mounted before the tube stiles are mounted to the surrounding structure, as the access to the bottom screw holes is blocked when the frame is installed into its final place. This makes repairs and adjustments of the threshold hard to perform, which is important to note before final installation.

Screws used for the installation of the threshold is mentioned in Table 4.13 and the detailed drawings for the holes made in the threshold is found in Appendix D in the drawing NEWPSD_PRT04.

Table 4.13 - Components required to mount the threshold to the tube stiles.

Component	*Parts per mounting point*	*Mounting points*	*Total No. of parts*
Metal bolt 5.4mm	2	x 2	= 4

4.2.7.5 Hinges to outer and inner frame

Being a standard piece offered by ASSA ABLOY, the hidden hinges have a pre-determined methodology for mounting developed by the company for standard usage. This method has been copied for the sake of following the instructions, to ensure correct mounting.

To fit the hinges to the rest of the New Passdoor, there are three parts that need extra processing in advance. The parts are outer and inner frame stile, as well as tube stile, all located at the hinge side of the door. The manufacturing required is described in detail in three detail drawings, mentioned with explanation in Table 4.14 below and explanatory pictures of all the stiles in Figure 4.22 to Figure 4.24, together with an cross sectional assembly view in Figure 4.25. All detailed drawings are available in Appendix D.

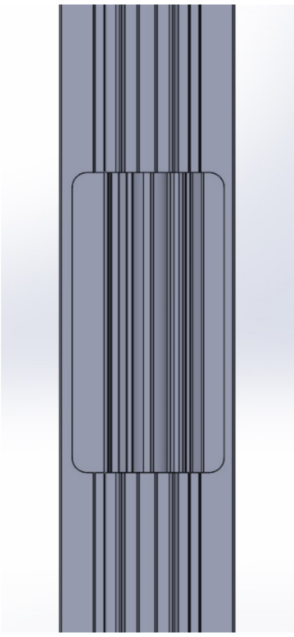

Figure 4.22 - Manufacturing for the hinge in the tube stile.

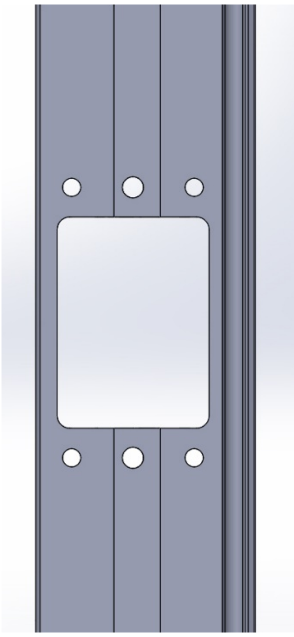

Figure 4.23 - Manufacturing for the hinge in the outer frame stile.

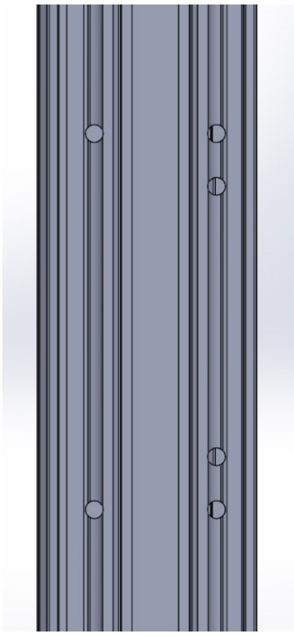

Figure 4.24 - Manufacturing for the hinge in the inner frame stile.

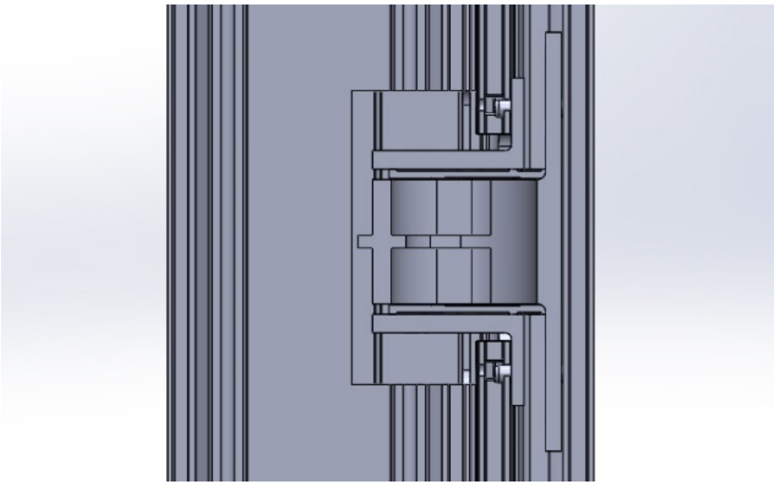

Figure 4.25 - Cross-sectional view of the hinge mounted to the three stiles, with the cutout in the three parts visible.

As seen by the detailed drawings mentioned in Table 4.14, there are three parts that require manufacturing before mounting the hinges, although the hinges are only attached to two parts (inner and outer frame). This is due to the body of the hinge being so big that it needs to fit inside both the frame stile and tube stile. The cutout in these parts for the body of the hinge is thus important to avoid interferences. A cross sectional view from two angles of the cutout is featured in Figure 4.25 below.

Table 4.14 - Listing of the detailed drawings required for processing of the mounts to the hinges.

Drawing	***Comment***
NEWPSD_DET08	Holes for hinge mount, inner frame stile
NEWPSD_DET03	Holes for hinge mount and cutout for hinge body, outer frame stile
NEWPSD_DET04	Cutout for hinge body, tube stile

As seen by the detailed drawings mentioned in Table 4.14, there are three parts that require manufacturing before mounting the hinges, although the hinges are only attached to two parts (inner and outer frame). This is due to the body of the hinge being so big that it needs to fit inside both the frame stile and tube stile. The cutout in these parts for the body of the hinge is thus important to avoid interferences.

To mount the hinges permanently, eight screws per hinge are required. These additional parts are mentioned below in Table 4.15.

Table 4.15 - Components required to mount the hinges to the inner and outer frame stiles.

Component	***Parts per mount (hinge)***	***Mounting points***	***Total No. of parts***
Metal bolt 4mm	8	x 4	= 32

4.2.7.6 Handle, lock box & lock plate.

The same way as the hinges have a specific and pre-determined way of being installed due to them being a finished product from ASSA ABLOY, the handle, lock box and lock plate are also components with clear instructions on installation and handling. The difference between these parts and the hinges, are that these have lower mechanical importance to the door, as the hinges hold the whole structure together and the handle is simply for usage and the lock box and plate are for safety and locking. In addition, the components are also necessary to fulfill the EN 12604 standard, mentioned in section 3.3.2, as suitable devices to enable movement are required for approval of the door. However, they are just as important to achieve the functionality of a fully functional door.

Manufacturing of the frame stiles in order to prepare for the mounting of these parts are shown in Appendix D and the specific drawings are listed below in Table 4.16.

Table 4.16 - Listing of the detailed drawings required for processing of the mounts to the handle, lock box and lock plate.

Drawing	*Comment*
NEWPSD_DET02	Holes and cutout for lock plate, outer frame stile
NEWPSD_DET05	Holes and cutout for lock box, inner frame stile (side)
NEWPSD_DET06	Holes and cutout for lock box, inner frame stile (front)

To mount the handle, lock box and lock plate permanently, additional screws and bolts are required. Follow assembly instructions by ASSA ABLOY for these instructions and parts.

4.3 Mechanical testing

After finishing modelling the New Passdoor, deciding on parts used in the assembly and how to connect them to each other, there is a need to evaluate how this door behaves in real life. This includes testing and calculation of whether the door withstands loads and forces, as well as evaluating how and in what ways it can be optimized to find a good balance between used parts and minimizing risk for potential deformation.

4.3.1 **Component durability**

The components mentioned earlier to be exposed to risk for deformations and excessive forces are the frame stiles (especially the OH1082P frame stiles) and the hinges in the door. To make educated decisions on whether certain parts of the door must be reinforced further beyond the initial planned assembly or how many of a specific part is needed in the door, these components need to be analyzed mechanically and in terms of strength.

The mechanical analysis is featured in this section, where the frame stiles and the hinges are evaluated. Later in the report, at section 4.3.3, the conclusions from the mechanical testing will be examined and evaluated to optimize the design.

4.3.1.1 Frame stile stiffness

In previous designs of the OH1042P industrial gates, the frame stiles that have also been chosen for this project have proven themselves as offering sturdiness enough for the construction to be structurally stable. Through this, it can be deducted that the 42 mm stiles will also be sturdy enough to give the New Passdoor for OH1042P stability and avoid warping, hanging or other defects on the doors rigidity. This has been achieved, even though the stile has a softer plastic piece inside of it, that would potentially be the first component in the stile to deform due to the plastic material having a much lower yield stress than the metal.

However, the frame and tube stiles in Passdoors for OH1082P gates has, as mentioned in 0, a recommended design with an around three times as long plastic cold bridge inside of the metal stiles. Increasing the distance between the metal components of the stile with a plastic material, creates a concern for component stability to avoid hanging or deformation of the door. This requires further investigation.

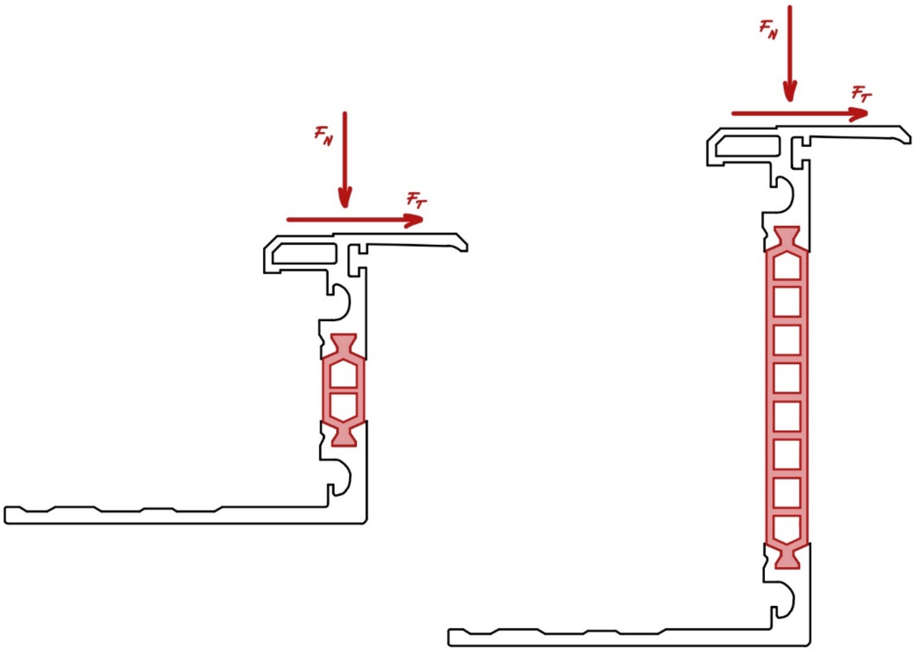

Figure 4.26 - Cross section of the stile showing the two cold bridge configurations, with normal and transverse forces marked out.

Methodology to investigate stability of the altered design plastic middle piece, depends on what type of deformation is risked in the elongated cold bridge. Looking at a cross section of the frame stiles, as shown in Figure 4.26, forces normal to the door plane will create a compression of the cold bridge (marked out in the figure as the force F_H). A compression is not that bad for the design through, as it is placed in the cold bridges direction of propagation, which is well reinforced. However, if the two metal components in the stile shifts in transverse to each other, either due to a shift from a horizontal force or from a transverse load (F_T), the cold bridge will most likely distort, example shown in Figure 4.27. A potentially good methodology to compare distortion between the stiles in the OH1042P door and the OH1082P variation, is to measure difference in warping angle. Theory behind calculations of warping angle is expressed in section 3.5.2 regarding twisting and torsion.

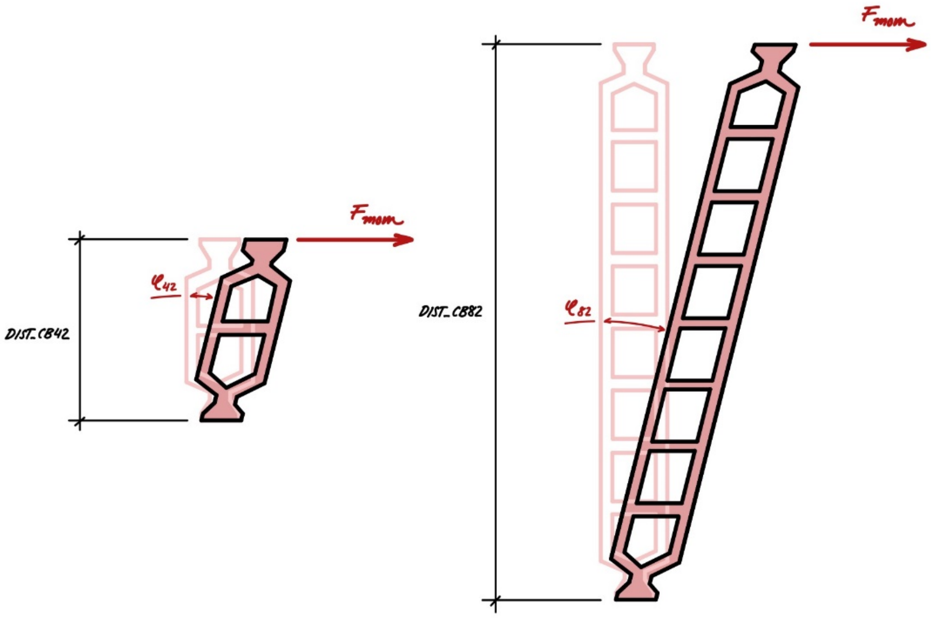

Figure 4.27 - Close-up of the two cold bridge configurations, visualizing the warping angle of the component after a torque is applied.

Due to the material used in the cold bridge (PA 6.6 according to documentation from ASSA ABLOY) being isotropic in all directions, the equations from section 3.5.2 can be used to determine a ratio between the warping angle φ_{42} and φ_{82}, to see how much more the OH1082P Passdoor will distort than the OH1042P. However, the actual warping angle for the two configurations is also of interest, which is why the same equation is used to define this value.

$$\varphi = \frac{M_v * L_{stile}}{G_{PA\,6.6} * I_v}$$

To get a value of a potential severe deformation of the cold bridge, a scenario is established where the entire weight of the Passdoor is focused in one point on the longest frame stile in the inner door frame, creating a moment twisting the cold bridge. Optimally the scenario is not realistic as the weight of the door is preferably distributed evenly along the door stiles, but as the gravitational pull of door’s own dead weight is the largest force, this is a good maximum force to use to calculate an extreme but somehow realistic deformation.

The weight in this case as well as the length of the stile is dimensioned for three size configurations of the door: minimum, maximum and a middle size, where the longest inside frame stile and the heaviest door configuration (OH1082P) is chosen for all calculations. Values for the moment of inertia I_v is retrieved from a CAD model of the two cold bridges and found in Appendix A. Material properties for the cold bridge include elastic modulus, Poisson's ratio, which give the shear modulus. These values are retrieved from the ASSA ABLOY product library and given in Table 4.17.

Table 4.17 - Material properties for the material in the cold bridge.

Variable	*Suffix*	*Value*	*Unit*
Elastic modulus	*E*	*2.62e+09*	*[N/m²]*
Poisson's ratio	*v*	*0.340*	*[-]*
Shear modulus	*G*	*9.776e+08*	*[N/m²]*

Calculations to determine a maximum deformation angle are performed in Microsoft Excel and found in Appendix B. The results regarding the warping deformation of the two cold bridges are shown in Table 4.18 below.

Table 4.18 - Deformation angles at several different door configurations when the deforming force is the door's own weight.

Door	*Variable*	*Min. Door*	*Mid. Door*	*Max. Door*
OH1042P	φ_{42}	*0,08°*	*0,12°*	*0,18°*
OH1082P	φ_{82}	*0,54°*	*0,86°*	*1,28°*

4.3.1.2 Hinge stress limit

In terms of optimization, an important decision to be made is the number of hinges needed for the new Passdoor design. Because the entire door floats in the air, being held up exclusively by the hinges, these points are prone to extreme stress. Optimally to reduce the number of parts in the design, only two hinges are needed for a well-dimensioned door (most optimal would be a single hinge, but this is not realistically possible for obvious reasons), but as some configurations of the door are very heavy, the strength and stability of the hinges must be tested. A method for testing this is to develop several test cases for the different doors to evaluate what weight loads are put on the doors hinges at different door configurations and compare the data to the strength of an individual hinge.

To evaluate the strength of an individual hinge, computer aided software is utilized to analyze at what loads on the hinge the material reaches its yield stress. If dimensioned in a way that the yield strength of the part is not exceeded, risk for deformation is minimized. The hinges selected in section 4.2.5.4 is the hinge model with drawing number D001059280-001, which itself consists of seven parts in four different materials. These materials with additional yield strength values are shown in Table 4.19 below, data from ASSA ABLOY's product library.

Table 4.19 - Materials used in the hinge.

Material	***Technical Name***	***Yield strength*** *[N/m²]*	***Used in***
Aluminum	AA380-0 F	159 000 000	Mounts & arm
Stainless steel	AISI 304	517 017 000	Rot. axis
Polyamide	PA 6.6 GF25	103 648 888	Flat inserts
Nylon	Nylon 6/10	139 043 000	Round inserts

As shown in the diagram, the plastic materials PA 6.6 GF25 and Nylon 6/10 are the ones with the lowest yield strength values. However, it can be suspected that when the hinges are exposed to a weight load, it is not the plastic inserts that are subject to the greatest load, but the mounts, the arm inside of the hinge and the rotational axis pin. These parts are made from aluminum and stainless steel, with higher yield strengths. This suspicion though must be confirmed later when doing deformational analysis with computer aided software.

To follow standards, a safety factor will also be added to proof the door from failure. The factor is taken from section 3.3.2 where the standard EN-12604 states that the safety factor regarding yield stress for a Passdoor shall be minimum 2.0 for calculation purpose. This gives the new maximum yield stress in the material stated in Table 4.20.

Table 4.20 - Maximum allowes stress for the materials used, with safety factor included.

Technical Name	***Maximum allowed stress*** *[N/m²]*
AA380-0 F	***79 500 000***
AISI 304	*258 508 500*
PA 6.6 GF25	*51 824 444*
Nylon 6/10	*69 521 500*

To compare stress inside of the hinge to the yield strength of the individual parts, the method used will be to expose the hinge to loads reaching from very low to very high and compare the stress data to the yield strength. To simplify calculations, forces will only be placed in one coordinate direction at a time and the maximum door opening angle will be reduced to 90° instead of 100° for the same reason. Loads evaluated will be vertical, horizontal (in the door's direction of propagation when closed and opened) and a force perpendicular to the door plane when fully open.

Firstly, horizontal forces on the hinges are evaluated, including both a closed and fully opened state (approximated to 90° as mentioned above). A graphic representation of the horizontal forces evaluated are shown in Figure 4.28.

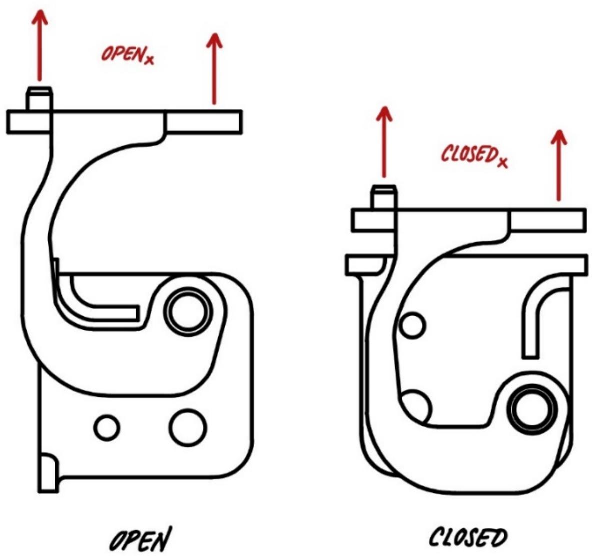

Figure 4.28 - Graphic representation of the horizontal forces on the hinges when open and closed.

The forces tested ranges from 400 N to -400 N as the force will be both dragging and pushing the hinge, with an increment of 40 N between tests. Positive value of the force corresponds to the direction shown in Figure 4.28 The results regarding maximum stress inside of the hinge are shown in Table 4.21 below, obtained from computer aided testing in SolidWorks Simulation.

Table 4.21 - Maximum stress in the hinge at ten different loads, with numbers in bold marking out threshold values of maximum load before reaching yield stress.

$FORCE$ $[N]$	$CLOSED_X$ $[N/m^2]$	$OPEN_X$ $[N/m^2]$
400	*1,253E+08*	*1,252E+08*
360	*1,127E+08*	*1,126E+08*
320	*1,001E+08*	*1,001E+08*
280	*8,754E+07*	*8,753E+07*
240	***7,499E+07***	***7,499E+07***
200	*6,247E+07*	*6,247E+07*
160	*4,995E+07*	*4,995E+07*
120	*3,745E+07*	*3,745E+07*
80	*2,496E+07*	*2,496E+07*
40	*1,247E+07*	*1,247E+07*
0	*0*	*0*
-40	*8,061E+06*	*8,059E+06*
-80	*1,614E+07*	*1,613E+07*
-120	*2,423E+07*	*2,423E+07*
-160	*3,234E+07*	*3,233E+07*
-200	*4,047E+07*	*4,046E+07*
-240	*4,861E+07*	*4,859E+07*
-280	*5,677E+07*	*5,675E+07*
-320	*6,495E+07*	*6,492E+07*
-360	***7,314E+07***	***7,311E+07***
-400	*8,135E+07*	*8,132E+07*

Secondly, vertical forces on the hinges are evaluated, once again including both a closed and fully opened (approximated to 90° as mentioned above). A graphic representation of the horizontal forces evaluated are shown in Figure 4.29.

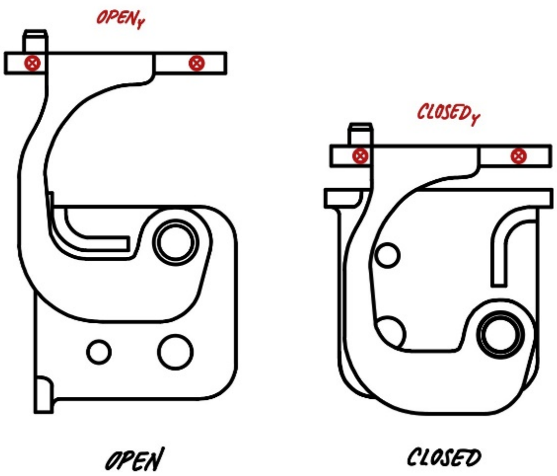

Figure 4.29 - Graphic representation of the vertical forces on the hinges.

The forces tested ranges from 400 N to 800 N, with an increment of 40 N between tests. The results regarding maximum stress inside of the hinge are shown in Table 4.22 below, obtained from computer aided testing.

Table 4.22 - Maximum stress in the hinge at ten different loads, with numbers in bold marking out the highest load before reaching yield stress.

$FORCE$ $[N]$	$OPEN_Y$ $[N/m^2]$	$CLOSED_Y$ $[N/m^2]$
400	*5,023E+07*	*4,528E+07*
440	*5,526E+07*	*4,980E+07*
480	*6,028E+07*	*5,433E+07*
520	*6,529E+07*	*5,886E+07*
560	*7,036E+07*	*6,339E+07*
600	***7,536E+07***	*6,791E+07*

640	*8,038E+07*	*7,244E+07*
680	*8,540E+07*	***7,696E+07***
720	*9,041E+07*	*8,149E+07*
760	*9,546E+07*	*8,602E+07*
800	*1,005E+08*	*9,055E+07*

Lastly, forces on the hinges perpendicular to the door blade towards the opening direction of the door are evaluated, including a fully opened version of the door. A graphic representation of the horizontal forces evaluated are shown in Figure 4.30.

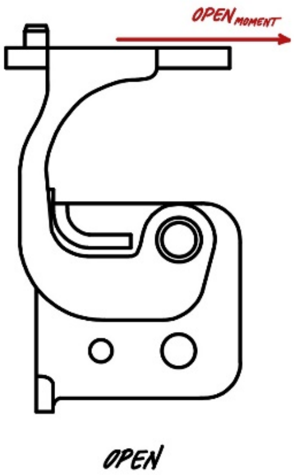

Figure 4.30 - Graphic representation of the force perpendicular to the door plane on the hinges.

The forces tested ranges from 20 N to 200 N, with an increment of 20 N between tests. The results regarding maximum stress inside of the hinge are shown in Table 4.22 below, obtained from computer aided testing.

Table 4.23 - Maximum stress in the hinge at ten different loads, with numbers in bold marking out the highest load before reaching yield stress.

$\boldsymbol{FORCE}$ $[N]$	$\boldsymbol{CLOSED_X}$ $[N/m^2]$
20	*1,508E+07*
40	*3,015E+07*
60	*4,521E+07*
80	*6,027E+07*
100	***7,529E+07***
120	*9,033E+07*
140	*1,054E+08*
160	*1,204E+08*
180	*1,354E+08*
200	*1,504E+08*

As shown by Table 4.21, Table 4.22 and Table 4.23, approximate values for loads making the hinges reach yield strength have been assessed. However, the approximations are very rough and sometimes has a certainty interval of 40 N, which in this case can make a big impact on the result. Since the computer aided software cannot be used for optimization purpose, an effort to get more exact answers is done through linear interpolation between the data values around the maximum allowed yield stress in the material. The method linear interpolation is described more detailed in 3.5.3 and the calculations are performed in Microsoft Excel, shown in Appendix C. The answers are given in Table 4.24 below.

Table 4.24 - Approximate values for extreme values where yield stress is reached, using linear interpolation.

$\boldsymbol{POSITION}$	$\boldsymbol{FORCE}$ $[N]$
$CLOSED_{X_{MAX}}$	*254,37*
$CLOSED_{X_{MIN}}$	*-390,99*
$OPEN_{X_{MAX}}$	*254,39*
$OPEN_{X_{MIN}}$	*-391,13*
$CLOSED_{Y}$	*632,99*

$OPEN_Y$	*702,43*
$OPEN_Z$	*105,60*

Thanks to the safety factor being 2.0, as mentioned above, the estimates obtained from the linear interpolation will be considered valid enough to be used for dimensional optimization.

To reach an understanding of where the stresses on the hinges will be located at the different maximum forces stated in Table 4.24, deformational analysis was performed using finite element method software in SolidWorks Simulation. The results are shown with pictures in Appendix C, with an excerpt of the seven main cases below in Figure 4.31 to Figure 4.44. Analysis consists of both deformation and stress analysis, to determine both highest allowed load and how much the part is deformed. The pictures show that the suspicion regarding what parts that deform were correct and only the parts made out of aluminum and stainless steel is deformed.

Note that in the pictures, extreme and excessive deformations of the parts inside of the hinge are visible, that shapes the hinge to an unrecognizable shape where parts are intersecting and surfaces are bent. This though is a result of the deformation scale used by the software, which in many cases are over 10 000:1. It can be noted that the largest deformation discovered by the software is 0.511 mm and occurs when the hinge is open and exposed to a horizontal pushing force of $391\ N$.

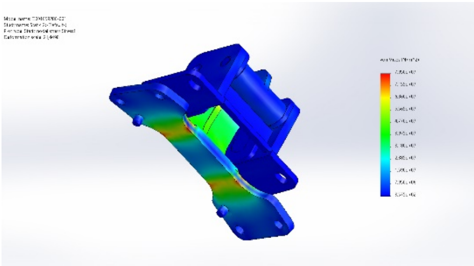

Figure 4.31 - Stress analysis in a closed hinge at maximum allowed horizontal load.

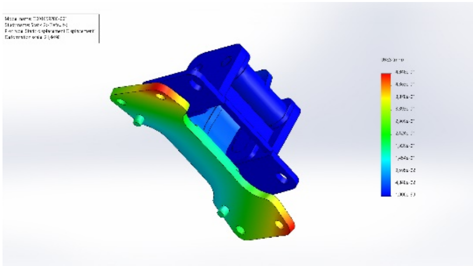

Figure 4.32 - Displacement analysis in a closed hinge at maximum allowed horizontal load.

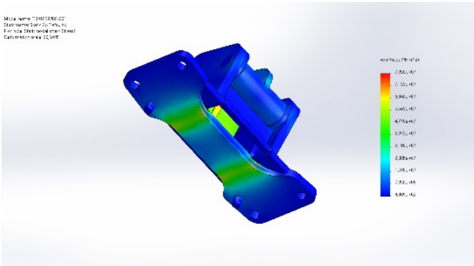

Figure 4.33 - Stress analysis in a closed hinge at minimum allowed horizontal load.

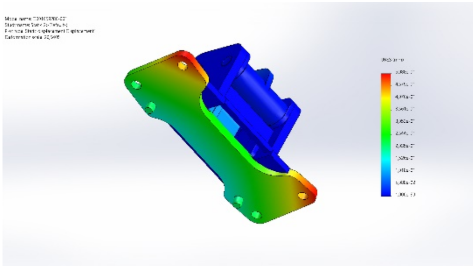

Figure 4.34 - Displacement analysis in a closed hinge at minimum allowed horizontal load.

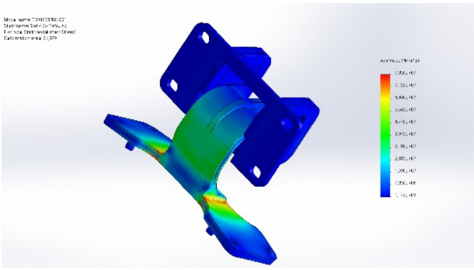

Figure 4.35 - Stress analysis in an open hinge at maximum allowed horizontal load.

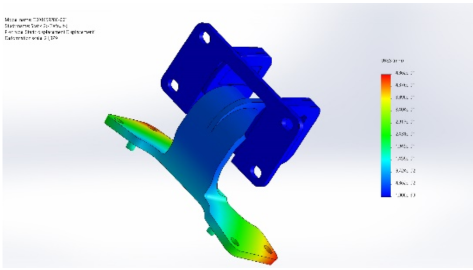

Figure 4.36 - Displacement analysis in an open hinge at maximum allowed horizontal load.

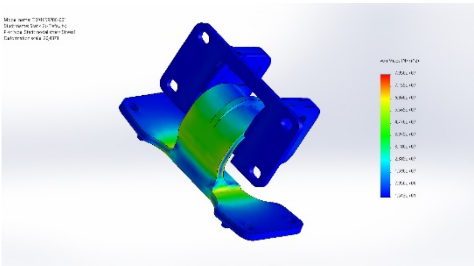

Figure 4.37 - Stress analysis in an open hinge at minimum allowed horizontal load.

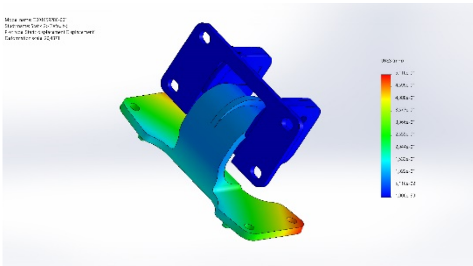

Figure 4.38 - Displacement analysis in an open hinge at minimum allowed horizontal load.

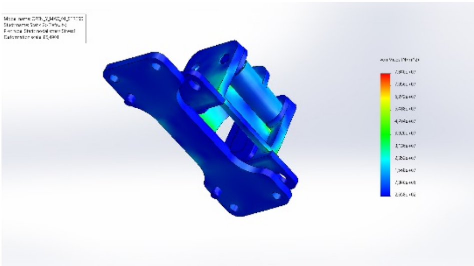

Figure 4.39 - Stress analysis in a closed hinge at maximum allowed vertical load.

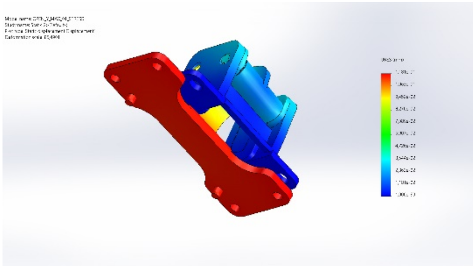

Figure 4.40 - Displacement analysis in a closed hinge at maximum allowed vertical load.

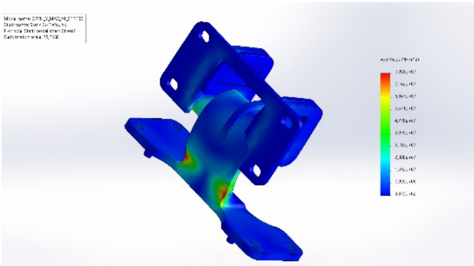

Figure 4.41 - Stress analysis in an open hinge at maximum allowed vertical load.

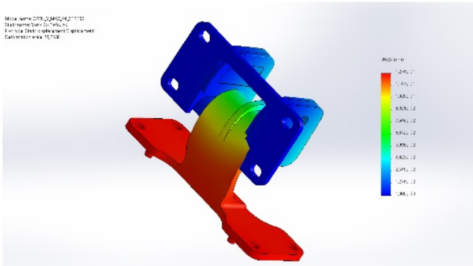

Figure 4.42 - Displacement analysis in an open hinge at maximum allowed vertical load.

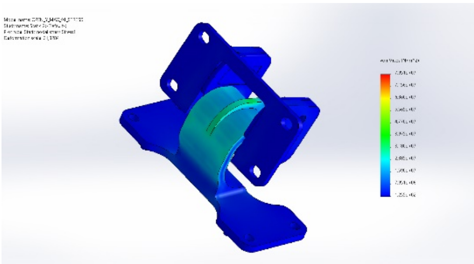

Figure 4.43 - Stress analysis in an open hinge at maximum allowed load normal to the door.

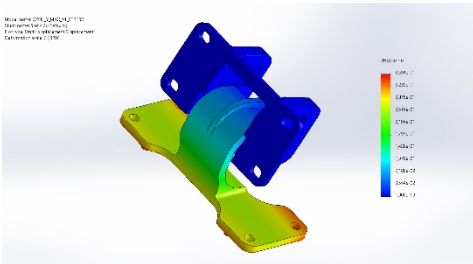

Figure 4.44 - Displacement analysis in an open hinge at maximum allowed load normal to the door.

4.3.2 **Load scenarios**

To test the door properly to prevent it from breaking or deforming during use, three life-like scenarios have been established where the door is exposed to extreme stress levels. Performing a number of tests was a requirement from ASSA ABLOY, where the tests are simulations of:

- **Dead weight load** – scenario when the only force acting on the door is the gravitational force of the door's weight itself, being calculated when the door is both opened and closed.

- **Load at handle** – scenario when a load at 35kg is placed on the handle of the door to simulate a small child hanging at the handle, being calculated when the door is both opened and closed.

- **Wind load** – scenario when the door is exposed to a load from a wind blowing consistently at the open door.

Methods used for testing of the different scenarios are a combination of the manual calculations of force and deformation done previously in section 4.3.1, combined with computer analysis testing of the built CAD-model assembly of the door.

In finite element method simulation of the different loads on the door, the model has been simplified to make simulations easier. This simplification and adaptation to computer analysis covers removal of parts with intricate geometries that do not affect the result of the analysis, as well as sealings, screws and mounting parts.

4.3.2.1 Dead weight load

The dead weight load test simulates a scenario when the door is both opened and closed and the only force affecting the structure is the self-weight of the door. The purpose of the dead weight load test is to identify maximum and minimum load of the door weight itself and calculate the forces acting on the hinges. This information can after this be used to determine what number of hinges are needed and if these will be deformed during use of the door.

To calculate these forces on the hinges, the forces are calculated for two conditions of the door, when fully closed shut fully opened. These opening angles are 0° and 100° respectively, but for simplification purpose, the maximum angle will be adjusted to 90°, which makes the system better adapted for static mechanical calculations as the direction of the door follows the direction of the axes of the coordinate system. As a starting point, the calculations are performed using a reference height for placement of the hinges along the frame stile, which is positioned 350 mm from the top and bottom of the door on all size configurations. It is a reasonable position to mount the hinges on if the calculations show that it is structurally possible.

The horizontal and vertical force the hinge reference heights are exposed for are calculated for three size configurations of the door (minimum, maximum and a mid-size used in the physical model) with three different weights. Center of mass of the entire door is positioned in the center of the door blade, and the total mass is calculated through adding the weight of the panels and the frame stiles together.

- Panel weight is calculated through multiplying the panel surface area with the surface density of the two panel thicknesses.
- Frame stile weight is calculated digitally with help of SolidWorks software.

Deviations on total weight due to processing of the components, or addition of details such as hinges and handles are seen as negligible. Safety factor to proof the door from failure is set to 2.0, as mentioned in section 3.3.2 as part of the EN-12604 standard regarding mechanical properties of Passdoors. As the dimensions of the door are variable, clarification of the included measurement variables are shown in Figure 4.45.

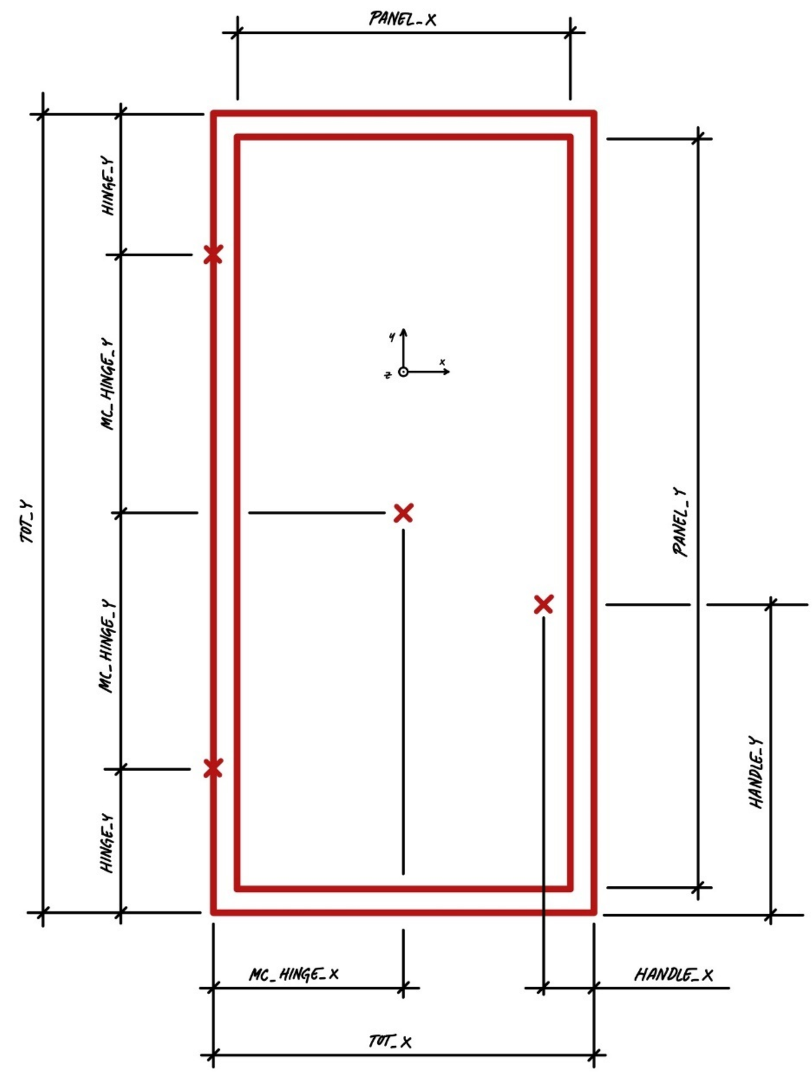

Figure 4.45 - Global measurements for the door out of which calculations are based.

Analyzing the mechanical aspects of the New Passdoor starts with a free body schematic sketch of the state of the door. In this scenario, the only forces acting on the door are horizontal and vertical forces from the hinges, as well as the weight of the door. The free body sketch is the same for both a 0° closed door as for a 90° fully opened door, with the difference that the horizontal x axis and normal z axis get swapped.

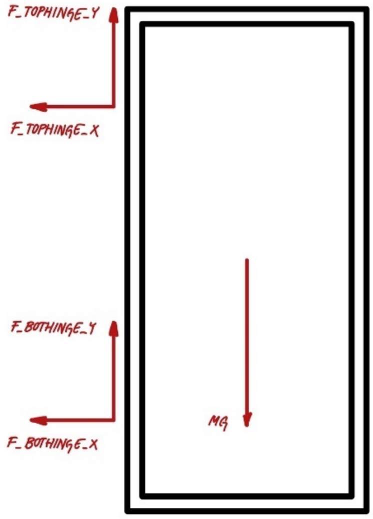

Figure 4.46 - Schematic representations of what forces are acting on the New Passdoor when only dead weight is measured.

For the horizontal and vertical directions, neutral and static force equilibrium can be established, as well as moment equation around the lower hinge. Forces are shown in Figure 4.46.

$$(\uparrow): \quad F_{TOPHINGE_Y} + F_{BOTHINGE_Y} - mg = 0$$

$$(\rightarrow): \quad F_{TOPHINGE_X} + F_{BOTHINGE_X} = 0$$

$$(\overset{\frown}{BOTHINGE}): \quad -MG * MC_{HINGE_X} + F_{TOPHINGE_X} * 2 * MC_{HINGE_Y} = 0$$

Solving the equations gives the forces acting on the hinges holding the door, these are shown for the 12 different configurations in Table 4.25 below.

Table 4.25 - Numeric values of forces on hinges when only dead weight load is calculated *[N].*

			TOP HINGE			***BOTTOM HINGE***		
config.	***size***	***ang.***	***horiz. force*** $F_{TOPHINGE,X}$	***vertic. force*** $F_{TOPHINGE,Y}$	***normal force*** $F_{TOPHINGE,Z}$	***horiz. force*** $F_{BOTHINGE,X}$	***vertic. force*** $F_{BOTHINGE,Y}$	***normal force*** $F_{BOTHINGE,Z}$
OH1042P	*min*	*0°*	*76,06*	*130,82*	*0*	*-76,06*	*130,82*	*0*
	mid	*0°*	*158,37*	*197,97*	*0*	*-158,37*	*197,97*	*0*
	max	*0°*	***229,43***	***267,03***	*0*	***-229,43***	***267,03***	*0*
	min	*90°*	*0*	*130,82*	*76,06*	*0*	*130,82*	*-76,06*
	mid	*90°*	*0*	*197,97*	*158,37*	*0*	*197,97*	*-158,37*
	max	*90°*	*0*	***267,03***	***229,43***	*0*	***267,03***	***-229,43***
OH1082P	*min*	*0°*	*88,10*	*151,53*	*0*	*-88,10*	*151,53*	*0*
	mid	*0°*	*183,27*	*229,09*	*0*	*-183,27*	*229,09*	*0*
	max	*0°*	***264,98***	***301,40***	*0*	***-264,98***	***301,40***	*0*
	min	*90°*	*0*	*151,53*	*88,10*	*0*	*151,53*	*-88,10*
	mid	*90°*	*0*	*229,09*	*183,27*	*0*	*229,09*	*-183,27*
	max	*90°*	*0*	***301,40***	***264,98***	*0*	***301,40***	***-264,98***

Note that the vertical forces $F_{TOPHINGE_Y}$ and $F_{BOTHINGE_Y}$ are equally big as the vertical MG force on the door. This relationship gives the sum of these two forces. However, we do not have any information on how the internal distribution of force between these two hinge reference heights. In an optimal assembly, the hinges are placed in such a way that they are exposed for even amounts of force, but if the door starts to hang or is assembled in the slightest inaccurate way, one of the hinges will be subject for a larger force than the other, up to the entire weight of the door.

To keep in mind regarding this matter, the safety factor of the door will as previously mentioned still be 2.0, which means that the hinges will be designed to withstand this force peaks due to extremely incorrect installation. We can also assume that the door will be assembled in a good enough way that the force distribution variance will not be larger than marginally. Finally, addition of more hinges to the heavier configurations of the door will lower the risk of this occurring.

4.3.2.2 Load at handle

The load at handle test simulates a scenario when the door is opened and closed as a weight of 35kg is hung from the door handle. The purpose of this test is to increase the loads on the door apart from the dead weight, as tested in section 4.3.2.1 to proof the door from tough handling or someone putting a lot of their weight on the door handle. This information can after this be used to determine what number of hinges are needed and if these will be deformed during use of the door.

The calculations to identify the horizontal and vertical forces on the hinges are like what was calculated as dead weight load in section 4.3.2.1, but with the extra load added with a point of mass other than the center of mass of the door itself. Just like before, the safety factor for the yield strength is 2.0 as mentioned in section 3.3 regarding industry standards and smaller deviations from the weight is negligible.

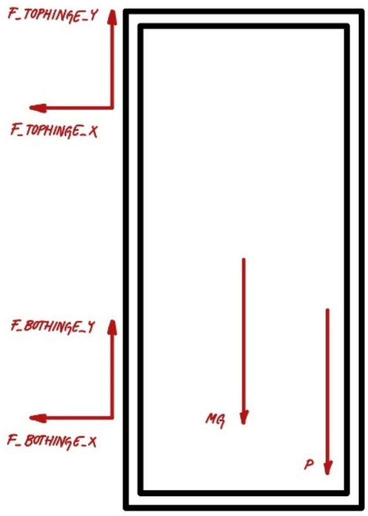

Figure 4.47 - Schematic representations of what forces are acting on the New Passdoor when a weight *P* is placed on the door handle.

The hinge forces are calculated by establishing a static force equilibrium as well as a moment equation around the lower hinge. This is shown in Figure 4.47.

$$(\uparrow): \quad F_{TOPHINGE_Y} + F_{BOTHINGE_Y} - mg - P = 0$$

$$(\rightarrow): \quad F_{TOPHINGE_X} + F_{BOTHINGE_X} = 0$$

$$(\overset{\frown}{BOTHINGE}): \quad F_{TOPHINGE_X} * 2 * MC_{HINGE_Y} - MG * MC_{HINGE_X} - P * (TOT_X - HANDLE_X) = 0$$

Solution of the equation system gives the forces acting on the hinges holding the door, these are shown for the 12 different configurations in Table 4.26 below.

Table 4.26 - Numeric values of forces on hinges used when the weight of the door together with an additional weight at the handle of 35kg is added *[N]*.

			TOP HINGE			BOTTOM HINGE		
config.	***size***	***ang.***	***horiz. force*** $F_{TOPHINGE, X}$	***vertic. force*** $F_{TOPHINGE, Y}$	***normal force*** $F_{TOPHINGE, Z}$	***horiz. force*** $F_{BOTHINGE, X}$	***vertic. force*** $F_{BOTHINGE, Y}$	***normal force*** $F_{BOTHINGE, Z}$
OH1042P	*min*	*0°*	*267,27*	*605,36*	*0*	*-267,27*	*605,36*	*0*
	mid	*0°*	*425,43*	*739,64*	*0*	*-425,43*	*739,64*	*0*
	max	*0°*	***517,92***	***877,76***	*0*	***-517,92***	***877,76***	*0*
	min	*90°*	*0*	*605,36*	*267,27*	*0*	*605,36*	*-267,27*
	mid	*90°*	*0*	*739,64*	*425,43*	*0*	*739,64*	*-425,43*
	max	*90°*	*0*	***877,76***	***517,92***	*0*	***877,76***	***-517,92***
OH1082P	*min*	*0°*	*279,30*	*646,75*	*0*	*-279,30*	*646,75*	*0*
	mid	*0°*	*450,32*	*801,87*	*0*	*-450,32*	*801,87*	*0*
	max	*0°*	***553,47***	***960,50***	*0*	***-553,47***	***960,50***	*0*
	min	*90°*	*0*	*646,75*	*279,30*	*0*	*646,75*	*-279,30*
	mid	*90°*	*0*	*801,87*	*450,32*	*0*	*801,87*	*-450,32*
	max	*90°*	*0*	***960,50***	***553,47***	*0*	***960,50***	***-553,47***

4.3.2.3 Wind load

The wind load test simulates a scenario in which a wind with a sustained velocity is creating a load on the door blade, in which it is investigated how large the wind load force on the hinge section will be. In the scenario, the door is fully opened and the wind load is placed perpendicularly on the door's flat vertical surface, as a perpendicular wind creates the largest total projected surface area for the wind to affect. The wind load test is relevant in a scenario when the Passdoor is accidentally left open for a longer time and a strong wind is blowing and pushing the door, which the design should be strong enough to hold for. A wind load test and method to prevent movement from wind loads on the door is also necessary according to the standard EN 12604, mentioned in section 3.3.2 and classes repeated in Table 4.27. According to Swedish Meteorological and Hydrological Institute, wind loads can be classified into three classes, explained below (SMHI, 2021).

Table 4.27 - Clarification of wind classes with associated velocities (SMHI, 2021).

Class	*Wind speed [m/s]*	*Note*
1	*>21*	Very powerful winds.
2	*>25*	Damage on buildings and risk for flying objects.
3	*>30*	Dangerous to stay outside. Extensive damage on buildings.

Danger for buildings and structures occurs at wind velocities rises above 30 m/s, also known as Class 3 (SMHI, 2021). The wind load calculations will be performed up to wind velocities this high. Additionally, to investigate wind loads at lower wind velocities, a breeze of 2.5 m/s and a stronger wind at 10 m/s is added for the calculations.

To simplify the calculations of the test, the maximum angle to open the door will be limited to 90° and not the hinges actual maximum opening angle 100°. The reason for this will be due to the calculations being simplified placing the forces along the coordinate system. However, the opening angle of the door is not important in this test if the wind is perpendicular to the door surface.

Additionally, the thickness and weight of the door is not of importance to these wind load calculations, as it is only the surface area of the door that affects the total wind load. The calculations will also only be performed on an opened door to test the strength of the maximum opening angle of the door. A closed door will also be exposed to load when a wind is blowing on it, but as the door is then pressed onto the outer frame which is assumed to be fixed in the rest of the building or surrounding gate, this test lacks relevance for the test of the hinges.

The wind load on a flat surface depends on the surface area, the wind velocity and the density of the air, together with a drag coefficient (Baer, 2018).

$$F_{wind} = A\,\rho_{air}\,C_d\,v^2$$

The density of air at sea level ρ_{air} can be estimated to approximately 1.229 $\frac{kg}{m^3}$ (Engineering Toolbox, 2011) and the drag coefficient for a flat surface like the door in question is 1.0 with a dimensionless unit (Baer, 2018).

As the Passdoor is hung up around the hinge, a rotational moment is created when the wind pushes the door, which must be met by an equally big moment in the attachment of the hinges. The moment created by the wind also varies along the horizontal axis of the door as it varies in distance from the rotational point, which creates the need for integrational equation solving. However, as the door and its inner frame has a fixed center of mass with a constant distance from the center of revolution, the total wind force can be placed as a single force in the center of mass, as shown in Figure 4.48. As the number of hinges is yet to be evaluated, the hinge force will be expressed for the entire hinge section, which can afterwards be divided with the desired number of hinges for load per hinge.

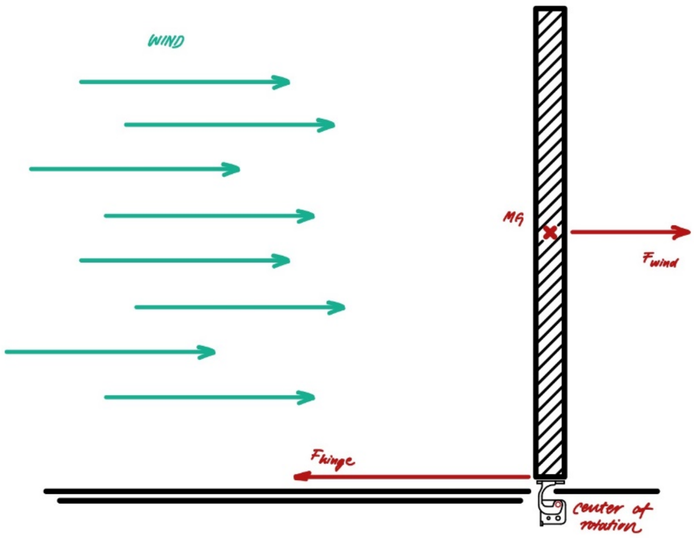

Figure 4.48 - Schematic representations of the forces acting on the Passdoor when a sustained wind load is placed on the surface of the opened door.

Through calculations performed in Microsoft Excel, the load on the hinge section at the different variations were calculated. The calculations are shown in Appendix B and the results are shown in Table 4.28 below.

Table 4.28 - Wind load force on the New Passdoor [N].

Class	*Wind speed [m/s]*	*Min. Door [N]*	*Mid. Door [N]*	*Max. Door [N]*
Breeze	*2.5*	*12,76*	*20,28*	*28,02*
Wind	*10*	*204,11*	*324,46*	*448,31*
1	*21*	*900,14*	*1430,85*	*1977,07*
2	*25*	*1275,70*	*2027,85*	*2801,97*
3	*30*	***1837,01***	***2920,10***	***4034,83***

As seen in Table 4.28, the load on the hinge section coming from the wind load on the open door, stays considerably well under 30 N at the lowest wind load at 2.5 m/s. But as seen in the table as well, the load increases rapidly as the wind load increases and at Class 1 wind load the load in the hinge section goes from 1 kN up to 2 kN depending on door size. At Class 3 with 30 m/s wind strength, the load on the largest possible door configuration reaches above 4 kN.

After having decided the total wind load on the door, the corresponding braking force in the hinge is calculated, which is done through a moment equation around the center of rotation in the hinge, as seen in Figure 4.40.

$$(\widehat{RC}): \quad -F_{WIND} * RC_{DOOR} + F_{HINGE} * RC_{HINGE} = 0$$

The calculations give the hinge loads F_{HINGE} and are shown below in Table 4.29 for further examination.

Table 4.29 - Wind load force absorbed by the hinge section in the New Passdoor [N].

Class	***Wind speed*** *[m/s]*	***Min. Door*** *[N]*	***Mid. Door*** *[N]*	***Max. Door*** *[N]*
Breeze	*2.5*	*160,66*	*372,95*	*635,11*
Wind	*10*	*2 570,63*	*5 967,17*	*10 161,80*
1	*21*	*11 336,49*	*26 315,22*	*44 813,53*
2	*25*	*16 066,45*	*37 294,81*	*63 511,24*
3	*30*	*23 135,69*	*53 704,52*	*91 456,18*

4.3.3 **Conclusions from mechanical testing**

After researching component durability and loads in the static system in previous sections 4.3.1 and 0, conclusions can be made regarding dimensioning of the New Passdoor by comparing data and optimizing performance. The calculations and motivations behind these decisions are made in the following sections.

4.3.3.1 Stile modification

As discovered in section 4.3.1.1 regarding stile stiffness, the increased cold bridge in the New Passdoor with an 82 mm thickness results in a significantly higher risk for warping deformation in the stile. From the calculations made in section 4.3.1.1 it is apparent that the deformation in the OH1082P frame stile is almost seven times more than in the OH1042P door. This is a dramatic increase and can result in severe deformation of the door.

However, it is not completely clear how large the initial deformation is in the OH1042P door frame stiles. If this door is not deformed at all, the thicker option might not be either. In addition, the calculated maximum warping in the heaviest and largest door is 1.28°, which results in the displacement calculated in the equation below.

$$displacement = \sin(1.28°) * 60\ mm = 1.34\ mm$$

A displacement of maximum 1.34 mm in a door that is 2440 mm high is fraction of the overall size of the system. Additionally, a potential vertical shifting of the door of this size will not create any interferences of any kind, due to the clearance between the door and the outer frame being larger than the displacement ($12\ mm$ clearance compared to $1.34\ mm$ displacement). A recommendation though, is to make physical tests with a full-scale prototype to determine the actual deformation when using the thicker cold bridge.

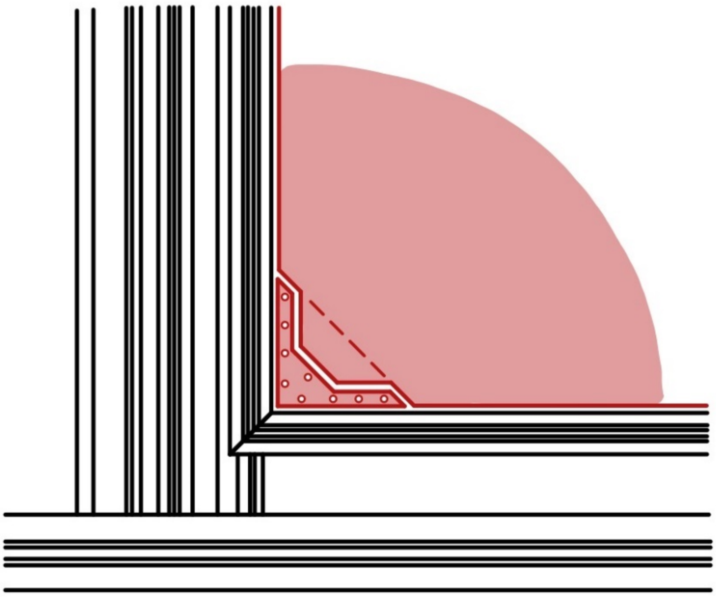

Figure 4.49 - Example of corner reinforcement in the inner frame, with examples of a corner cutout.

Although, if the deformation of the door is not at all desirable, a way to minimize the shifting is to add reinforcements that keep the door in its intended shape. For example, mounts inside the door frame corners with a 90° design, might be able reduce the shifting of the components in relation to each other. An example of what this could look like is shown in Figure 4.49. This adds a minimum of four extra part of the door assembly, along with pop rivets and screws to mount it in place. If it is possible to create a door without this added reinforcement, it is recommended for the reason of reducing cost and assembly times.

4.3.3.2 Hinge layout

Discovered in 4.3.1.2 regarding the stress limits of hinges and 0 discussing different scenarios of load on the door above, both maximum load capacity before reaching yield stress in all directions and actual load placed on the hinges by the door have been discovered. To reach a conclusion regarding dimensioning of the door, in terms of using a correct number of hinges, these now known variables can be compared to dimension the door to avoid deformation.

Initially, vertical and horizontal forces on the hinges have been examined in 4.3.2.1 and 4.3.2.2, where both the forces from the door's own weigh, as well as the own weight together with an external weight on the handle have been examined. Both investigations are relevant for the project, but when dimensioning for the correct number of hinges, the variation with the most loads will be of most interest. In this case, that is the calculations with the extra load at the door's handle, which makes the results in Table 4.26 relevant for dimensioning in this case.

To get a clear perception of what the simulation results about the hinges recommend, the actual force in all the hinges in the tested door can be compared by division with the highest allowed load in the corresponding direction of the hinge. The directions tested firstly is horizontal in both positive and negative direction, as well as vertical force, all tested both on a closed and an open door.

$$\frac{F_{ACTUAL\ LOAD\ ON\ A\ HINGE}}{F_{MAX\ ALLOWED\ LOAD\ ON\ A\ HINGE}} = HINGE\ COVERAGE$$

Calculations are made with help from Microsoft Excel using a goal-seek function, featured in Appendix B in its entirety and the results are shown below in Table 4.30.

Table 4.30 - Evaluation of amount of hinges needed at every position and in every direction.

PASSDOOR	*STATE*	*HINGE*	*MIN. DOOR*	*MID. DOOR*	*MAX. DOOR*
OH1042P	***closed***	$F_{TOPHINGE_X}$	*1,05*	*1,67*	***2,04***
		$F_{BOTHINGE_X}$	*0,68*	*1,09*	*1,32*
		$F_{TOPHINGE_Y}$	*0,96*	*1,17*	*1,39*
		$F_{BOTHINGE_Y}$	*0,96*	*1,17*	*1,39*
	open	$F_{TOPHINGE_X}$	*1,05*	*1,67*	***2,04***
		$F_{BOTHINGE_X}$	*0,68*	*1,09*	*1,32*
		$F_{TOPHINGE_Y}$	*0,86*	*1,05*	*1,25*
		$F_{BOTHINGE_Y}$	*0,86*	*1,05*	*1,25*
OH1082P	***closed***	$F_{TOPHINGE_X}$	*1,10*	*1,77*	***2,18***
		$F_{BOTHINGE_X}$	*0,71*	*1,15*	*1,42*
		$F_{TOPHINGE_Y}$	*1,02*	*1,27*	*1,52*
		$F_{BOTHINGE_Y}$	*1,02*	*1,27*	*1,52*
	open	$F_{TOPHINGE_X}$	*1,10*	*1,77*	***2,18***
		$F_{BOTHINGE_X}$	*0,71*	*1,15*	*1,42*
		$F_{TOPHINGE_Y}$	*0,92*	*1,14*	*1,37*
		$F_{BOTHINGE_Y}$	*0,92*	*1,14*	*1,37*

Seen from the results in Table 4.30, it is apparent that for most cases, the forces at the hinge position far exceeds what one single hinge can take before reaching maximum allowed stress. Only for the smallest door configuration in both OH1042P and OH1082P doors, the loads are close to being low enough for just a single hinge at both reference heights to handle. But even then, the horizontal forces are slightly too large for a single hinge to handle.

However, as the forces are too big for only two hinges holding the entire door to handle, a solution is to increase the number of hinges on both hinge reference heights from one to two. By maintaining the same reference distance from the top and bottom of the door (here set as 350 mm) a set of two hinges can be mounted with a small and equal distance to the reference height, shown in Figure 4.50.

Provided that the hinges are mounted correctly, they will then split the load between each other, according to general laws of statics mechanics, as mentioned in section 3.5.1 about solid mechanics. By doing this, none of the hinges will be exposed to a larger stress than allowed.

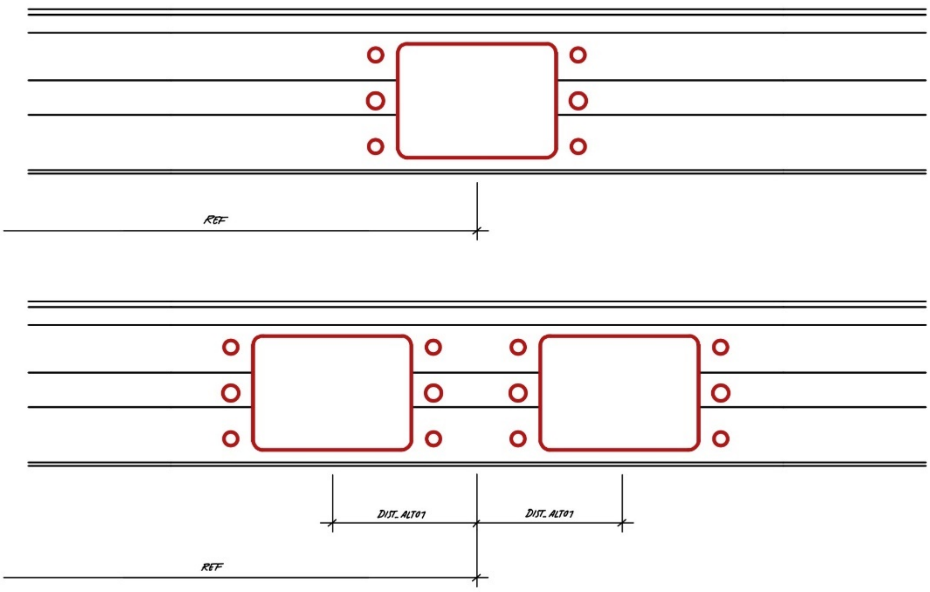

Figure 4.50 - Adjustment of one of the mounting positions on the outer frame stiles, to fit two hinges instead of one at each mounting point.

Worth mentioning is also that the hinge layout suggested by this solution is not the only layout possible. For example, changing the reference distance from the edges of the stile, or mounting the hinges with equal distances to each other along the whole stile hinge section is also an option, see Figure 4.51 for visual example. However, hanging the door with hinges clustered at top and bottom leads to no additional complications in comparison to other layout variants, and having two hinges close to each other increases the strength of that region of the door. This can be positive in terms of proofing for burglary and breaking into the Passdoor. Thus, the layout selected for further development will be two hinges at both reference heights.

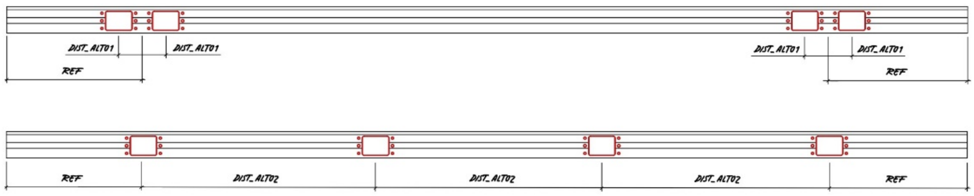

Figure 4.51 - Alternative mounting layout for the hinges along the frame stile.

Additionally, note that the smallest configuration of the door puts a very small load in some directions on the hinge reference heights, in some configurations below the need for even a single hinge. Putting two hinges in every location might seem like over-dimensioning the smaller configurations of the Passdoor excessively. Yet, as the positive horizontal force in the top hinge exceeds the single hinge limit even at the smallest and lightest door configuration, which validates the need for more than one hinge at both hinge reference heights.

The only configurations of the Passdoor where the need for hinges exceeds two at each hinge reference height is according to Table 4.30, the top hinge at the largest door configuration where the dragging force goes up to 2.18 times the hinge need. These are marked out in bold in Table 4.30. This, according to 3.5.1 regarding solid mechanics and section 0 regarding the forces at the hinge reference heights, is directly linked to the width of the door, whereas increased horizontal distance between the hinges and the door's center of mass directly affects the horizontal force. To compensate for this, additional hinges need to be added when the door is sized beyond a certain door width.

Calculations to reach a threshold value for the maximum allowed door width are performed in Microsoft Excel and based on the calculations from 4.3.2.2, with a variable door width. The stile weight is approximated to the heaviest configuration and the height is set to maximum. The width at which the need for hinges exceeds two is according to calculations in Microsoft Excel, shown in Appendix B, is at 1 410,9 mm. Thus, a reasonable maximum allowed width when using only two hinges is 1 400 mm. For widths over 1 400 mm, possible solutions could be adding one extra hinge at both hinge reference heights (to have three in total at both ends of the hinge stile) or to place a single middle hinge at the hinge stile.

To cut cost and simplify the door for production and design, the background given in this section also marks out that a reasonable decision to make is to simply offer Passdoors only with four hinges. The tradeoffs doing this will mainly be:

- Slightly over-dimensioning of the smallest door configurations.
- Limiting the maximum width of the door from 1 495 mm to 1 400 mm.

Benefits from this decision would be simplifying production of the Passdoors, as no special variations requiring a modified number of hinges needs to be designed. Avoiding having to make these calculations and special detailed drawings for every produced door with a width over 1 400 mm cuts design and production cost. Additionally, is it is assumed that the maximum and minimum dimensions of the door are ordered by customers occasionally and most orders are of doors with dimensions normally distributed somewhere in between the extreme dimensions, the decision will affect only a small number of customers.

4.3.3.3 Dimensioning for wind loads

Lastly, the force calculated as the wind load is the only dimensioning load not discussed in this section. By using the same methodology as for comparing the actual horizontal and vertical forces with the maximum hinge load limits in the same directions, this can be done with the wind loads. The calculations are performed in Microsoft Excel, shown in Appendix B with results shown in Table 4.31.

Table 4.31 - Results from calculations regarding appropriate number of hinges in relation to wind loads on different dimensions of the door.

Class	*Wind speed [m/s]*	*Min. Door [N]*	*Mid. Door [N]*	*Max. Door [N]*
Breeze	*2.5*	*1,52*	*3,53*	*6,01*
Wind	*10*	*24,34*	*56,51*	*96,23*
1	*21*	*107,35*	*249,20*	*424,38*
2	*25*	*152,15*	*353,18*	*601,44*
3	*30*	*219,09*	*508,57*	*866,08*

As seen by the results in Table 4.31, the smallest available door already requires an extreme number of 24 hinges to withstand a persistent 10 m/s wind, which is an excessive and a non-realizable solution in terms of assembly, outlook, over-dimensioning in relation to the loads in other directions as well as price. The need for almost 900 hinges in the largest door to withstand a 30 m/s storm is also a ridiculous number of hinges that is both unrealistic in terms of design and cost.

To further analyze what would happen if a strong wind is placed on one of the larger doors, the wind force from a 10 m/s wind on a maximum size door was simulated on the hinges using computer aided software with finite element method analysis in SolidWorks Simulation. The results are shown in Figure 4.52 and Figure 4.53.

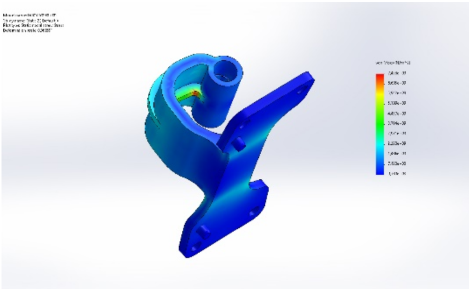

Figure 4.52 - Stress analysis in an open hinge at a load perpendicular to the door from a 10 m/s wind.

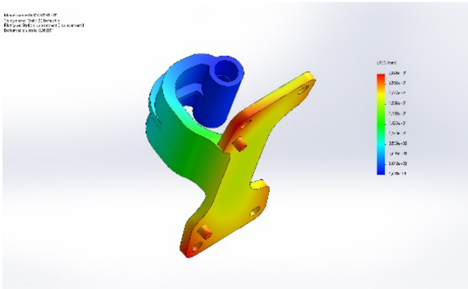

Figure 4.53 - Displacement analysis in an open hinge at a load perpendicular to the door from a 10 m/s wind.

To get a better view of the deformed parts of the hinge under the load, only the hinge arm was shown in Figure 4.52 and Figure 4.53, which was also the part of the hinge most deformed. The results show constant stresses over 1 GN/m^2 at many places throughout the component, which is much higher than the yield stress of 159 MN/m^2 which means that the point will most likely deform severely and potentially break. A stress concentration near the rotational axis goes as high as 7,428 GN/m^2, which is far beyond what is acceptable in the part. Thus, stopping the wind load with only hinges is not possible.

A more reasonable decision, is to move the force perpendicular to the door blade originating from the wind load, putting it somewhere else than on the hinges. Adding doorstops to either the ground or the top of the Passdoor is a good option for distributing the wind load elsewhere than on the hinges.

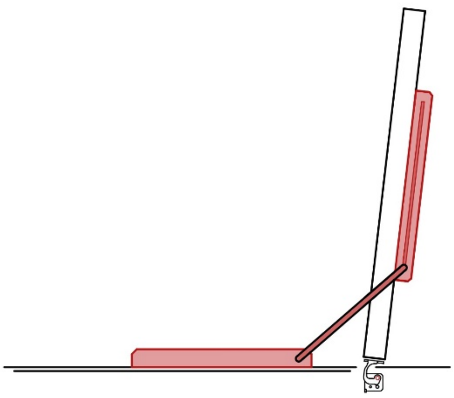

Figure 4.54 - Example of what a top doorstop could look like installed in the New Passdoor.

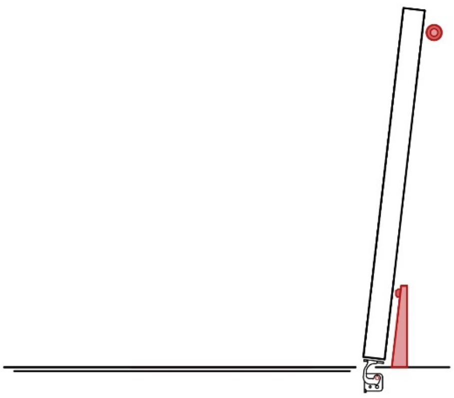

Figure 4.55 - Example of what two types of bottom doorstops could look like installed in the New Passdoor.

Additions of doorstops can make the door withstand high wind loads, without putting strain on the hinges. In addition, it makes the door fulfill the standard EN 12604, giving the door a stop that makes it stay in its terminal positions. In Figure 4.54 and Figure 4.55, an example of what these stops could look like are featured.

As the Passdoor is placed in an industrial environment though, floor space is important, which makes it more compelling to add a door stop to the top of the door than to the bottom. If this stop can manage the entire wind load, it is preferrable to only use that. A top doorstop available for use in the ASSA ABLOY product library, good for use in the new Passdoor, is the ES104H door stop. It is placed in the top outer and inner frame stiles and limits the door from opening more than intended. The same door stop can be used for all door dimension configurations and both OH1042P and OH1082P Passdoors. The requirements for the door stop is additional mounting manufacturing of the top inner and outer frame stiles, along with screws and rivets for permanent mounting. The product recommended is shown below in Figure 4.56.

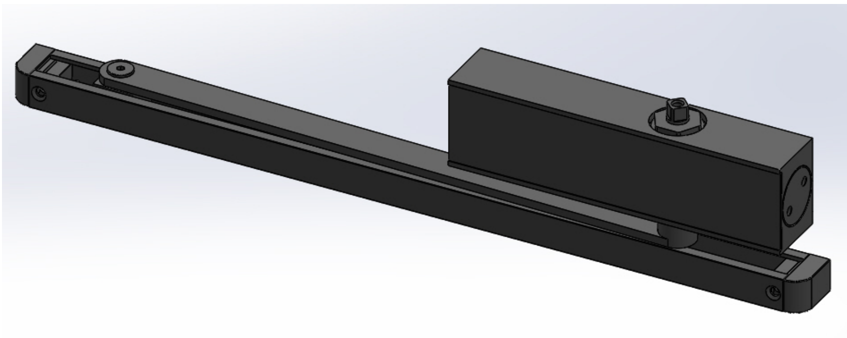

Figure 4.56 - Door stop recommended for use in the new Passdoor.

The door stop recommended for further implementation into the Passdoor is retrieved from ASSA ABLOY's file management center, with the drawing numbers shown in Table 4.32. The CAD file is a SolidWorks assembly, but only the top files used are mentioned in this report.

Table 4.32 - Specifications of what doorstops are added to the New PSD.

	Passdoor for OH1042P	*Passdoor for OH1082P*
Top door stop	D001020538-001	D001020538-001

5 Discussion

In this section the project result, progression and findings are discussed. Suggestions on how this project can be continued are also brought up.

5.1 Result

This Master Thesis has resulted in the finalized prototype design of two Passdoors for industrial gates OH1042P and OH1082P produced by ASSA ABLOY Entrance Systems. Images of the two finished doors are shown in Figure 5.1 to Figure 5.8. The result includes part selection, finalized detailed drawings regarding the assembly, the included parts as well as the details for the two door configurations. Thus, both the primary goal and fallback goal established in section 1.2 has been fulfilled.

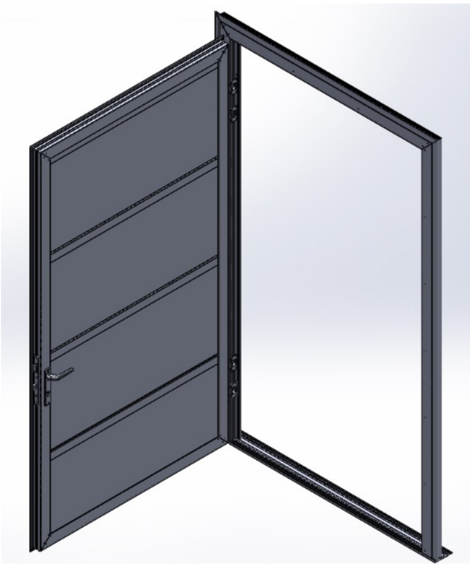

Figure 5.1 - Final design of the OH1042P Passdoor.

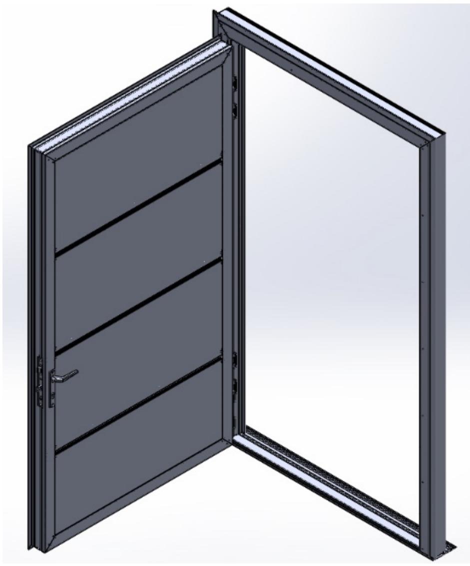

Figure 5.2 - Final design of the OH1082P Passdoor.

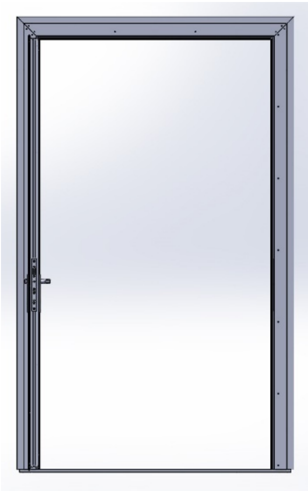

Figure 5.3 - Front view of the OH1042P Passdoor.

Figure 5.4 - Side view of the OH1042P Passdoor.

Figure 5.5 - Top view of the OH1042P Passdoor.

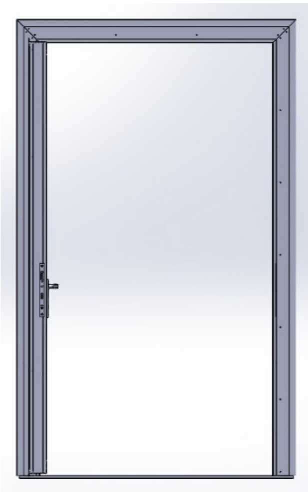

Figure 5.6 - Front view of the OH1082P Passdoor.

Figure 5.7 - Side view of the OH1082P Passdoor.

Figure 5.8 - Top view of the OH1082P Passdoor.

The drawings for the finalized concept doors can be found in Appendix D, regarding component design. In the drawings, all dimensions of the door have been presented, apart from the height and width of the doors, which is variable options for the customer. These new dimensions are presented in Table 5.1 below. Note that the maximum width has been slightly reduced in comparison to dimensions in section

4.1 regarding design limitations, due to findings in section 4.3.3.2 about the mechanical properties of the hinges.

Table 5.1 - New modified minimum and maximum dimensions for the New Passdoor,

DIMENSION	***MIN** [mm]*	***MAX** [mm]*
HEIGHT	*2076*	*2440*
WIDTH	*800*	*1400*

In addition, only two parts with a completely new design have been produced for the project, which are both available in Appendix D regarding detailed drawings. Also, the decision to equip every single configuration of the Passdoor with four hinges makes the design process simplified, easy for the company to produce and avoids wrong installations. Thus, no special configurations of some dimensions of the door ordered is required, but all are standardized according to the same set of design rules.

The project has also resulted in findings regarding the stiffness of the stiles in the OH1042P and OH1082P industrial gates, as well as mechanical properties regarding strength, yield stress and deformation of hinges under several different load scenarios. These findings can be used for future projects at ASSA ABLOY, using the same methods clearly described in this project.

5.2 Following of methodology and standards

In the beginning of the report, several methodologies, theories and standards were presented under section 3 regarding theory. Evaluation of how these have been followed is important, to determine whether they have been followed and if anything has been missed or left out of the project. In addition, it is also important to reach a conclusion about the standards if any additional work is left to do.

5.2.1 **Double diamond process & human centered design model**

The double diamond process model was very handy throughout the project, as it was clear that the model left room for finding the core problem of the assignment given by ASSA ABLOY Entrance Systems. Giving room for the discovery and developing phases was important, to not immediately establishing a problem or a solution, but being open to put time and effort into finding the best one.

Being on location for the first phase (discovery) vas very essential to get a grip of the products and systems offered by the company, as well as reading about and listening to information about the line of products that the New Passdoor will complement. The first phase was completed sometime between two and four weeks into the project but was gone back to several times to learn more about the product.

Second phase (definition) was especially important, since the New Passdoor will plug right into an already existing line of products. Reaching a problem definition occurred soon after completing the first phase of discovery but was re-visited several times for new components of the design, such as adding the tube stiles to the design of the doors later in the project.

Third phase (development) was the longest of the phases, which was also re-evaluated throughout the project. It turned out to be of help to combine the discovery phase with the development phase, in terms of building the digital model of the product in computer aided software SolidWorks, at the same time as learning about it. This also meant having to re-design many of the parts several times, for example after doing calculations and reaching conclusions regarding stability and component requirements. The parts re-evaluated in the development phase was doing component stability calculations instead of building a physical door for testing.

The last phase (delivery) was one of the shorter phases, which meant just packing the findings from former phases into the package that is this report and the actual Passdoors. This phase was completed about three weeks before the presentation date, not including final changes. Note that the solution presented by this report is not a finished product, but a good background for further development by ASSA ABLOY Entrance Systems.

The other methodology used (human centered design process) also proved very handy during the project, as the iterative process was applied repeatedly on the product. Re-designing the door over eight times and adding features after coming to new conclusions was good for the quality of the final product. This iterative process it not completely mirrored by this report, as it presents mainly the final result of the project.

5.2.2 **Standards**

The standards presented in the beginning of the project, in section 3.2.5, has been kept in mind during the project, but evaluation on how they have been followed as well as clarification on what must be done to qualify for following a specific standard, is evaluated in this section.

5.2.2.1 EN 13241 - Industrial, commercial and garage doors and gates – Product standard, performance characteristics

The standard EN 13241 is a summarizing standard, mostly referring to other standards that go more in-depth of specific characteristics of a Passdoor or industrial gate but does not have many specific characteristics that needs to be fulfilled itself.

The standard refers to EN 12604 and EN 12424, which are also described in this report, but also to EN ISO 140-3 regarding sound insulation, EN 12428 about thermal resistance, EN 12427 about air permeability and EN 12605 about durability testing, which are not mentioned in this report. These have not been mentioned in this project due to the project time being limited which meant that only the most crucial standards had time for evaluation but has to be taken into consideration for following work on the door.

5.2.2.2 EN 12604 - Industrial, commercial and garage doors and gates – Mechanical aspects – Requirements and test methods

The standard EN 12604 is the longest and most specific standard about the mechanics of Passdoors, being of great importance to the project. Many of the requirements presented by the standard have been managed throughout the project. This includes regulations regarding safety factors of components during calculations, addition of end stops to the door, unintentional movement protection, maximum load for opening and closing of the door, addition of movement-enabling devices (such as handles and lock box), permanent mounting of the door and tripping hazards. Also, using the standard parts from ASSA ABLOY, accidental cutting from sharp edges will be avoided.

What still needs oversight from the standard, is permanent addition of the mechanical stoppers, in-depth risk analysis of finger-pinching hazards and accidental cutting and addition of an anti-drop safety device. The standard also includes a verification procedure, that has to be performed on a physical door to be approved. The relevant tests from the standard are also mentioned in section 3.3.2.

5.2.2.3 EN 12425 - Industrial, commercial and garage doors and gates – Resistance to water penetration - Classification

The standard EN 12425 is a classification method for water penetration of the door, in which a class number is received after performance of physical tests of water spraying. This standard has not been mentioned in the report but is very relevant to perform when a physical door can be tested. Hopefully, as the doors features several rubber stripes of insulation along its frame, they can achieve a high water-penetration classification.

5.2.2.4 EN 12424 - Industrial, commercial and garage doors and gates – Resistance to wind load - Classification

Resistance to wind load has been a big part of the mechanical analysis of the door, in which it was found that only hinges are not enough to protect the door from deformation and movement coming from forces from strong winds. However, as new doorstops were added to the Passdoor design in the final part of the project, new tests must be performed to reach a conclusion regarding how much force these stops can withstand, to be classified in accordance with the EN 12424 standard, also shown in 3.3.4. A recommendation for the following work is to perform physical tests, as calculations proved to be not easy to get correct, to get a wind load resistance classification. Hopefully, the doors can achieve high classifications.

5.3 Future work

Following up from the result of this completed Master Thesis, ASSA ABLOY Entrance Systems are given a good background and starting point for getting the New Passdoor out to the market. However, until the final product reaches a consumer market, there are some recommended steps to be taken in order to finalize the product.

5.3.1 **Physical prototype testing**

To make sure that the decisions made in this master thesis on theoretical ground work in a real-life environment on a physical product, studies of an actual physical model must be conducted. Following the detailed drawings in Appendix D and the assembly instructions and details defined in section 4.2.7 regarding assembly features, the company is given a good roadmap for how physical prototypes of the two doors can be constructed.

The parts that need physical testing are mainly the stability and rigidity of the door, whereas the theoretical tests in section 0 regarding load scenarios need testing. In addition, there are tests needed to classify the Passdoor as having passed the standards, mentioned in section 3.3 regarding industry standards and elaborated on above in section 5.2.

5.3.2 **Finalizing design**

To prepare the product for construction and selling, the design of the Passdoor needs to be finalized. This includes adding the top door stop to the design in addition to potential minor changes decided on due to findings when building a real life prototype.

5.3.3 **Design of new tools**

As there are only two completely new parts designed for the New Passdoor, it is very easy to construct a prototype of the door and make cost calculations, as the other parts already exist and is just an order away. Especially since all parts for the OH1042P door is available, this version is easy to construct. The OH1082P door is harder to create concept models of though since many of the parts included need the new adjusted cold bridges. Detailed drawings of these parts are shown Appendix D.

As the cold bridges used in the OH1042P Passdoor are produced by the company Insulbar©, discussions need to be held regarding manufacturing of these new components. Both regarding cost of new tools for production of the components, but also how many parts need to be manufactured, together with a plan for assembly inside of the metal components of the stiles.

5.3.4 **Cost calculation**

Before the product is sold or manufactured, a complete cost analysis must be done. Both in order to set a fair price on the end product towards the consumer, but also in order to create a production line on which cost is monitored and make sure that the product profits the company.

A mention on cost is probably that the Passdoor for the OH1082P gates will be higher than the OH1042P gates, due to a potential higher manufacturing price of the new elongated cold bridges. How this is financed has to be determined, either if the number of sold doors will cover the cost of new tooling for the parts, or if the OH1042P Passdoor will help financing the tooling as well. It also has to be determined if the purchase of the new cold bridge tooling is worth it for the company, or if it will result in loss due to excessive cost in tooling. In conclusion, a deeper analysis cost related to these potential decisions must be performed.

5.4 Project progression

The project held the initial time frame, established within the first week of the Master Thesis. However, as unexpected setbacks occurred over the course of the project, the time plan had to be adjusted along the course of the project. The initial time plan can be seen in Appendix E.

One of the initial plans for the project, was to use the findings and construct a proof-of-concept physical door, that could be used for testing and evaluation. This part of the project was supposed to take place in the start of July, but what was not included in the plan from the start was the general industrial summer holidays that occurred during this period until two weeks before the projects end. Additionally, getting help with and approval from ASSA ABLOY Entrance Systems of the detailed drawings of the door before delivering finished drawings was hard, as the staff and supervisor in charge went on vacation. Thus, unfortunately not being able to construct a physical Passdoor as end of the Master Thesis project, resulting in a mostly theoretical project.

However, the inability to construct the physical door gave room for additional evaluation of the strength and durability of many of the parts in the New Passdoor, such as a deep analysis of the hinges and stiles, which is hopefully handy in future projects both regarding the New Passdoor, but also in other endeavors performed by ASSA ABLOY Entrance Systems.

Additionally, the COVID-19 pandemic also made a large impact over the course of the project. Getting from a situation in lockdown in the beginning of the project to more freedom of movement towards the end, the risks which accompanied the pandemic resulted in lots of unplanned work from home, with periods not being able to visit the site due to risk of infection. This also delayed some parts of the thesis, which had to be caught up during the project. This did not affect the end goal though.

Finally, it must be mentioned that a theoretical time plan and project methodology in the beginning of a project of the magnitude is very handy to structure the work but must be taken with a pinch of flexibility. Making and elaborate plan way in advance before going deeply into the project and seeing what challenges appear and what will take time and what will not, has the risk of being wrong. Additionally, going back and re-evaluating something that looked finished before does not follow the time plan, but is very good for the result. But this is the whole point of a Human Centered Design process, mentioned in section 3.2, where the iterative process gives a better result. This has been a very helpful insight in the project.

6 Conclusion

The scope of this Master Thesis has been to perform and conduct a product development process, regarding development of a New Passdoor for industrial gates and passages developed and sold currently by ASSA ABLOY. The main challenges of this project have been developing a solution that is as robust, while only using parts that already exist in the ASSA ABLOY product library, at the same time as trying to optimize cost. This has resulted a finished product that fits right into the existing ASSA ABLOY product ecosystem, being a good complement to the existing gate solutions offered by the company. By following up through both performing a deeper and more comprehensive cost analysis of the door, as well as trying out physical concept models for testing of the performance of the door and classification of standards, this project gives a good background and great value for future work with the new Passdoors and industrial gates by ASSA ABLOY.

As final words, I would like to express my gratitude for the opportunity and trust given to me by all the people involved at ASSA ABLOY Entrance Systems in this project. For me, this has been a great, very challenging and extremely rewarding experience, giving me insight in an interesting and relevant industry. As a gateway between the five years of studying at the Faculty of Engineering at Lund's University and the following working life, I am now excited and thrilled about what's to come in the professional life of an engineer.

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Appendix A – Cold bridge properties

Appendix A consists of data about the stiles used in the doors OH1042P and OH1082P, with a focus on mechanical properties. The data is computer generated and based on a cross-section of the beam, taken from CAD models of the details in SolidWorks.

A.1 Cold bridge properties – OH1042P

Section properties of the selected faces of *D001037639-001*

Area

$$= 70.73\ mm^2$$

Centroid relative to assembly origin: (mm)

$$X = 0.00$$
$$Y = 0.00$$
$$Z = 5000.00$$

Moments of inertia of the area, at the centroid: (mm^4)

$$L_{xx} = 350.42 \quad L_{xy} = 0.00 \quad L_{xz} = 0.00$$
$$L_{yx} = -100958.39 \quad L_{yy} = 166938.51 \quad L_{yz} = 0.00$$
$$L_{zx} = 0.00 \quad L_{zy} = 0.00 \quad L_{zz} = 351461.55$$

Polar moment of inertia of the area, at the centroid

$$= 2739.61\ mm^4$$

Angle between principal axes and assembly coordinate axes

$$= 0.00\ deg$$

Principal moments of inertia of the area, at the centroid: (mm^4)

$$I_x = 350.42$$
$$I_y = 2389.18$$

Moments of inertia of the area, at the output coordinate system: (mm^4)

$L_{xx} = 1768299245.90$	$L_{xy} = 0.00$	$L_{xz} = 0.00$
$L_{yx} = 0.00$	$L_{yy} = 1768301284.65$	$L_{yz} = 0.00$
$L_{zx} = 0.00$	$L_{zy} = 0.00$	$L_{zz} = 2739.61$

A.2 Cold bridge properties – OH1082P

Section properties of the selected faces of the modified *D001037639-001* for the OH1082P gate

Area

$$= 225.44\ mm^2$$

Centroid relative to assembly origin: (mm)

$$X = 0.00$$
$$Y = 0.00$$
$$Z = 5000.00$$

Moments of inertia of the area, at the centroid: (mm^4)

$$\begin{matrix} L_{xx} = 1469.03 & L_{xy} = 0.00 & L_{xz} = 0.00 \\ L_{yx} = 0.00 & L_{yy} = 71949.66 & L_{yz} = 0.00 \\ L_{zx} = 0.00 & L_{zy} = 0.00 & L_{zz} = 73418.69 \end{matrix}$$

Polar moment of inertia of the area, at the centroid

$$= 73418.69\ mm^4$$

Angle between principal axes and assembly coordinate axes

$$= 0.00\ deg$$

Principal moments of inertia of the area, at the centroid: (mm^4)

$$I_x = 1469.03$$
$$I_y = 71949.66$$

Moments of inertia of the area, at the output coordinate system: (mm^4)

$$L_{xx} = 5636172303.02 \quad L_{xy} = 0.00 \quad L_{xz} = 0.00$$
$$L_{yx} = 0.00 \quad L_{yy} = 5636242783.65 \quad L_{yz} = 0.00$$
$$L_{zx} = 0.00 \quad L_{zy} = 0.00 \quad L_{zz} = 73418.69$$

Appendix B – Calculations

0 features calculations used in section 4.3 about mechanical properties, to optimize the design. The calculations are performed in Microsoft Excel, utilizing the software's calculation features, out of which pictures have been inserted into this appendix. The contents are presented in Table 0.1 below.

Table 0.1 - Appendix contents.

Number	***Name***	***Featured in***
APPENDIX B.1	Calculations – Cold bridge	*4.3.3.1 Stile modification*
APPENDIX B.2	Statistics – Yield strength	*4.3.1.2 Hinge stress limit*
APPENDIX B.3	Scenario I – Dead Weight Load	*4.3.2.1 Dead weight load*
APPENDIX B.4	Scenario II – Load at handle	*4.3.2.2 Load at handle*
APPENDIX B.5	Scenario III – Wind load	*4.3.2.3 Wind load*
APPENDIX B.6	Results – Hinge dimensioning	*Hinge* layout

B.1 Calculations – Cold bridge

PROPERTIES

Dimensions of the parts included in the door

	MIN	MID	MAX	
TOT_X	800	1200	1495	[mm]
TOT_Y	2076	2200	2440	[mm]
STILERED	17	17	17	[mm]
PANEL_X	783	1183	1478	[mm]
PANEL_Y	2059	2183	2423	[mm]

MASS

Density of the two panel configurations OH1042 and OH1082

	OH1042	OH1082		
DENSITY	0,013	0,015		[g/mm^2

CONSTANT

Gravitational costant

G	9,82	

WEIGHT

Calculate weights of the three variations of door sizes, aligning center of mass is assum

	MIN_42	MID_42	MAX_42	
MG_STILE	55843,59	66256,72	76888,44	[mN]
MG_PANEL	205813,07	329680,55	457175,23	[mN]
MG_TOT	261,6566594	395,9372641	534,0636656	[N]

	MIN_82	MID_82	MAX_82	
MG_STILE	65574,72	77771,16	89292,67	[mN]
MG_PANEL	237476,62	380400,63	527509,88	[mN]
MG_TOT	303,05	458,17	616,80	[N]

COLD BRIDGE PROPERTIES

Dimensions of the two cold bridges

	OH1042P	OH1082P		
r	20	60		[mm]
I_v	166938,51	71949,66		[mm^4]

Material properties

	PA 6.6	
E	2620	[N/mm^2
v	0,340000004	[-]
G	977,6119377	[N/mm^2

CALCULATIONS

Calculating warping in the two cold bridge variations in the longest door stile.

	MIN_82	MID_82	MAX_82	
ra_42	0,08	0,12	0,18	[deg]
ra_82	0,54	0,86	1,28	[deg]

B.2 Statistics – Yield strength

Material properties

Yield strength	1,590E+08
Safety factor	2

Horizontal load (X)

FORCE	**CLOSED_X_POS**	**CLOSED_X_NEG**	**OPEN_X_POS**	**OPEN_X_NEG**	
40	1,247E+07	8,061E+06	1,247E+07	8,059E+06	[N/m^2]
80	2,496E+07	1,614E+07	2,496E+07	1,613E+07	[N/m^2]
120	3,745E+07	2,423E+07	3,745E+07	2,423E+07	[N/m^2]
160	4,995E+07	3,234E+07	4,995E+07	3,233E+07	[N/m^2]
200	6,247E+07	4,047E+07	6,247E+07	4,046E+07	[N/m^2]
240	**7,499E+07**	4,861E+07	**7,499E+07**	4,859E+07	[N/m^2]
280	8,754E+07	5,677E+07	8,753E+07	5,675E+07	[N/m^2]
320	1,001E+08	6,495E+07	1,001E+08	6,492E+07	[N/m^2]
360	1,127E+08	**7,314E+07**	1,126E+08	**7,311E+07**	[N/m^2]
400	1,253E+08	8,135E+07	1,252E+08	8,132E+07	[N/m^2]

Vertical load (Y)

FORCE	**CLOSED_Y**	**OPEN_Y**	
400	5,023E+07	4,528E+07	[N/m^2]
440	5,526E+07	4,980E+07	[N/m^2]
480	6,028E+07	5,433E+07	[N/m^2]
520	6,529E+07	5,886E+07	[N/m^2]
560	7,036E+07	6,339E+07	[N/m^2]
600	**7,536E+07**	6,791E+07	[N/m^2]
640	8,038E+07	7,244E+07	[N/m^2]
680	8,540E+07	**7,696E+07**	[N/m^2]
720	9,041E+07	8,149E+07	[N/m^2]
760	9,546E+07	8,602E+07	[N/m^2]
800	1,005E+08	9,055E+07	[N/m^2]

Rotational moment around hinge axis

FORCE	**OPEN_MOMENT**	
20	1,508E+07	[N/m^2]
40	3,015E+07	[N/m^2]
60	4,521E+07	[N/m^2]
80	6,027E+07	[N/m^2]
100	**7,529E+07**	[N/m^2]
120	9,033E+07	[N/m^2]
140	1,054E+08	[N/m^2]
160	1,204E+08	[N/m^2]
180	1,354E+08	[N/m^2]
200	1,504E+08	[N/m^2]

Maximum loads before yield strength (using linear interpolation)

	FORCE	
CLOSED_X_POS	254,37	[N]
CLOSED_X_NEG	390,99	[N]
OPEN_X_POS	254,39	[N]
OPEN_X_NEG	391,13	[N]
CLOSED_Y	632,99	[N]
OPEN_Y	702,43	[N]
OPEN_MOMENT	105,60	[N]

B.3 Scenario I – Dead weight load

PROPERTIES

Dimensions of the parts included in the door

	MIN	MID	MAX	
TOT_X	800	1200	1495	[mm]
TOT_Y	2076	2200	2440	[mm]
HINGE_Y	350	350	350	[mm]
STILERED	17	17	17	[mm]
MC_HINGE_X	400	600	747,5	[mm]
MC_HINGE_Y	688	750	870	[mm]
PANEL_X	783	1183	1478	[mm]
PANEL_Y	2059	2183	2423	[mm]

MASS

Density of the two panel configurations OH1042 and OH1082

	OH1042	OH1082	
DENSITY	0,013	0,015	[g/mm^2

CONSTANT

Gravitational costant

G	9,82

Calculate weights of the three variations of door sizes, aligning center of mass is assum

	MIN_42	MID_42	MAX_42	
MG_STILE	55843,59	66256,72	76888,44	[mN]
MG_PANEL	205813,07	329680,55	457175,23	[mN]
MG_TOT	**261656,66**	**395937,26**	**534063,67**	[mN]

	MIN_82	MID_82	MAX_82	
MG_STILE	65574,72	77771,16	89292,67	[mN]
MG_PANEL	237476,62	380400,63	527509,88	[mN]
MG_TOT	**303051,34**	**458171,79**	**616802,55**	[mN]

EQUILIBRIUM & TORQUE

Calculate horizontal (X) & vertical (Y) forces on the hinges

	MIN_42	MID_42	MAX_42	
F_TOPHINGE_X	76062,98	158374,91	229432,52	[mN]
F_BOTHINGE_X	-76062,98	-158374,91	-229432,52	[mN]
F_TOPHINGE_Y	130828,33	197968,63	267031,83	[mN]
F_BOTHINGE_Y	130828,33	197968,63	267031,83	[mN]

	MIN_82	MID_82	MAX_82	
F_TOPHINGE_X	88096,32	183268,72	264976,96	[mN]
F_BOTHINGE_X	-88096,32	-183268,72	-264976,96	[mN]
F_TOPHINGE_Y	151525,67	229085,89	308401,27	[mN]
F_BOTHINGE_Y	151525,67	229085,89	308401,27	[mN]

B.4 Scenario II – Load at handle

PROPERTIES

Dimensions of the parts included in the door

	MIN	MID	MAX	
TOT_X	800	1200	1495	[mm]
TOT_Y	2076	2200	2440	[mm]
HINGE_Y	350	350	350	[mm]
STILERED	17	17	17	[mm]
MC_HINGE_X	400	600	747,5	[mm]
MC_HINGE_Y	688	750	870	[mm]
PANEL_X	783	1183	1478	[mm]
PANEL_Y	2059	2183	2423	[mm]
HANDLE_X	34,5	34,5	34,5	[mm]
HANDLE_Y	946	946	946	[mm]

MASS

Density of the two panel configurations OH1042 and OH1082

	OH1042	OH1082	
DENSITY	0,013	0,015	[g/mm^2

CONSTANT

Gravitational costant

G	9,82	[m/s^2]

Calculate weights of the three variations of door sizes, aligning center of mass is assum

	MIN_42	MID_42	MAX_42	
MG_STILE	55843,59	66256,72	76888,44	[mN]
MG_PANEL	205813,07	329680,55	457175,23	[mN]
MG_TOT	**261656,66**	**395937,26**	**534063,67**	[mN]

	MIN_82	MID_82	MAX_82	
MG_STILE	65574,72	77771,16	89292,67	[mN]
MG_PANEL	237476,62	380400,63	527509,88	[mN]
MG_TOT	**303051,34**	**458171,79**	**616802,55**	[mN]

LOAD

Extra added load at handle to mimic the weight of a small child

MG_HANDLE	343700,00	[mN]

EQUILIBRIUM & TORQUE

Calculate horizontal (X) & vertical (Y) forces on the hinges

	MIN_42	MID_42	MAX_42	
F_TOPHINGE_X	267271,09	425429,81	517923,24	[mN]
F_BOTHINGE_X	-267271,09	-425429,81	-517923,24	[mN]
F_TOPHINGE_Y	605356,66	739637,26	877763,67	[mN]
F_BOTHINGE_Y	605356,66	739637,26	877763,67	[mN]

	MIN_82	MID_82	MAX_82	
F_TOPHINGE_X	279304,42	450323,62	553467,67	[mN]
F_BOTHINGE_X	-279304,42	-450323,62	-553467,67	[mN]
F_TOPHINGE_Y	646751,34	801871,79	960502,55	[mN]
F_BOTHINGE_Y	646751,34	801871,79	960502,55	[mN]

B.5 Scenario III – Wind load

PROPERTIES					
Dimensions of the parts included in the door					
		MIN	**MID**	**MAX**	
	TOT_X	800	1200	1495	[mm]
	TOT_Y	2076	2200	2440	[mm]
	RC_HINGE	34,5	34,5	34,5	[mm]
	RC_DOOR	434,5	634,5	782	[mm]
CONSTANT					
Wind speed, air density and					
	ra	1,229			[kg/m^3]
	cd	1,00			[-]
WIND SPEED					
Wind speeds based on classification from SMHI, as well as lower reference speeds.					
		VELOCITY			
	BREEZE	2,5			
	WIND	10			
	CLASS 1	21			
	CLASS 2	25			
	CLASS 3	30			
WIND LOAD					
Using equation for wind load, the force on the Passdoor is calculated.					
		MIN	**MID**	**MAX**	
	BREEZE	12,76	20,28	28,02	[N]
	WIND	204,11	324,46	448,31	[N]
	CLASS 1	900,14	1430,85	1977,07	[N]
	CLASS 2	1275,70	2027,85	2801,97	[N]
	CLASS 3	1837,01	2920,10	4034,83	[N]
Load on the hinge section is calculated					
		MIN	**MID**	**MAX**	
	BREEZE	160,66	372,95	635,11	[N]
	WIND	2570,63	5967,17	10161,80	[N]
	CLASS 1	11336,49	26315,22	44813,53	[N]
	CLASS 2	16066,45	37294,81	63511,24	[N]
	CLASS 3	23135,69	53704,52	91456,18	[N]

B.6 Hinge dimensioning

DATA

Forces in hinges

	MIN_42	MID_42	MAX_42	
F_TOPHINGE_X	267,27	425,43	517,92	[N]
F_BOTHINGE_X	-267,27	-425,43	-517,92	[N]
F_TOPHINGE_Y	605,36	739,64	877,76	[N]
F_BOTHINGE_Y	605,36	739,64	877,76	[N]

	MIN_82	MID_82	MAX_82	
F_TOPHINGE_X	279,30	450,32	553,47	[N]
F_BOTHINGE_X	-279,30	-450,32	-553,47	[N]
F_TOPHINGE_Y	646,75	801,87	960,50	[N]
F_BOTHINGE_Y	646,75	801,87	960,50	[N]

Hinge maximum loads

CLOSED_X_POS	254,37	[N]
CLOSED_X_NEG	- 390,99	[N]
OPEN_X_POS	254,39	[N]
OPEN_X_NEG	- 391,13	[N]
CLOSED_Y	632,99	[N]
OPEN_Y	702,43	[N]
OPEN_MOMENT	105,60	[N]

CALCULATIONS

Hinges required for each load configuration

	MIN_42_CLOSED	MID_42_CLOSED	MAX_42_CLOSED	
F_TOPHINGE_X	1,05	1,67	2,04	[-]
F_BOTHINGE_X	0,68	1,09	1,32	[-]
F_TOPHINGE_Y	0,96	1,17	1,39	[-]
F_BOTHINGE_Y	0,96	1,17	1,39	[-]

	MIN_42_OPEN	MID_42_OPEN	MAX_42_OPEN	
F_TOPHINGE_X	1,05	1,67	2,04	[-]
F_BOTHINGE_X	0,68	1,09	1,32	[-]
F_TOPHINGE_Y	0,86	1,05	1,25	[-]
F_BOTHINGE_Y	0,86	1,05	1,25	[-]

	MIN_82_CLOSED	MID_82_CLOSED	MAX_82_CLOSED	
F_TOPHINGE_X	1,10	1,77	2,18	[-]
F_BOTHINGE_X	0,71	1,15	1,42	[-]
F_TOPHINGE_Y	1,02	1,27	1,52	[-]
F_BOTHINGE_Y	1,02	1,27	1,52	[-]

	MIN_82_OPEN	MID_82_OPEN	MAX_82_OPEN	
F_TOPHINGE_X	1,10	1,77	2,18	[-]
F_BOTHINGE_X	0,71	1,15	1,42	[-]
F_TOPHINGE_Y	0,92	1,14	1,37	[-]
F_BOTHINGE_Y	0,92	1,14	1,37	[-]

Wind load

	MIN	MID	MAX	
BREEZE	1,52	3,53	6,01	[-]
WIND	24,34	56,51	96,23	[-]
CLASS 1	107,35	249,20	424,38	[-]
CLASS 2	152,15	353,18	601,44	[-]
CLASS 3	219,09	508,57	866,08	[-]

DOOR WIDTH						
Finding the width of the door where 2 hinges per location is not enough						
Dimensions of the parts included in the door						
		MAX				
	TOT_X	1,41				[mm]
	TOT_Y	2,44				[mm]
	HINGE_Y	0,35				[mm]
	STILERED	0,02				[mm]
	MC_HINGE_X	0,71				[mm]
	MC_HINGE_Y	0,87				[mm]
	PANEL_X	1,39				[mm]
	PANEL_Y	2,42				[mm]
	HANDLE_X	0,03				
	HANDLE_Y	0,95				
Density of the two panel configurations OH1042 and OH1082						
		OH1082				
	DENSITY	15				[g/m^2]
Gravitational costant						
	G	9,82				
Weights (stile approximation)						
	MG_STILE	76,8884396				
	MG_PANEL	507,0933562				
	MG_TOT	583,9817958				
Extra added load at handle to mimic the weight of a small child						
	MG_HANDLE	343,70				[mN]
Equation						
	RATIO	2,00				

Appendix C – Simulations

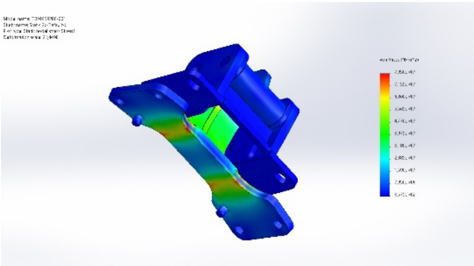
Appendix C consists of data obtained from computer-aided component durability testing of the hinges used in the New Passdoor. The contents of the appendix are pictures of the hinges after being exposed for the maximum load before a part of the component reaches yield stress. In addition, deformation visualization is also shown in the appendix. Four angles of every scenario are featured.

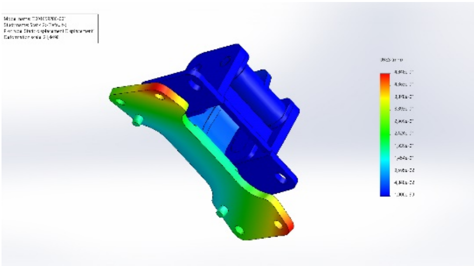
C.1 Closed hinge

The simulations of the closed hinge serves the purpose of analyzing the instance where the door is fully closed.

C.1.1 Positive horizontal load

Finite element method analysis using computer aided software SolidWorks Simulation of a closed hinge when exposed to the maximum positive force before the part reaches its yield stress. The force is placed from the screw holes on the flat mounting section and directed outwards from the hinge.





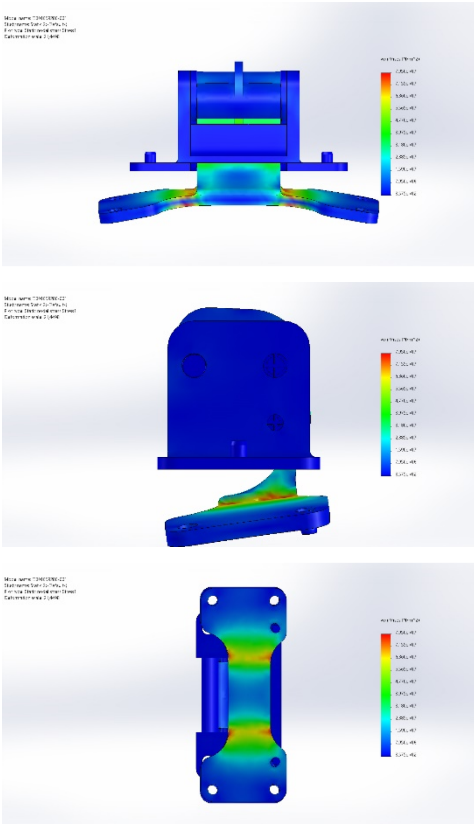


Figure 0.1 - Stress analysis seen from four different angles in a closed hinge at maximum positive horizontal load.

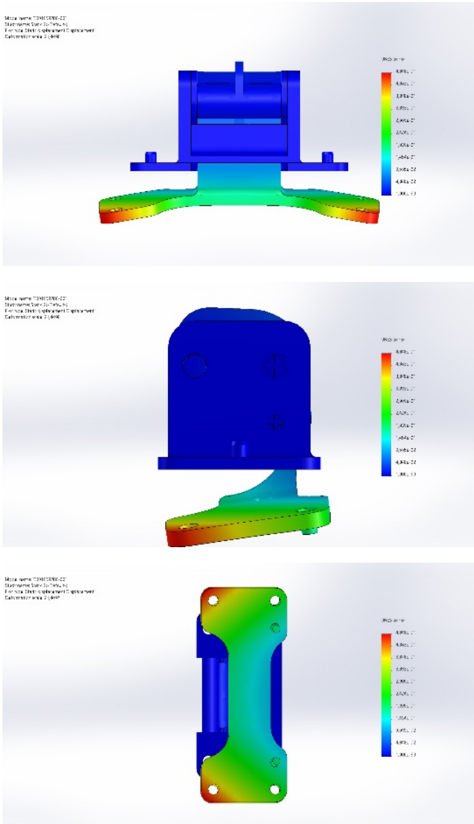


Figure 0.2 - Deformational analysis seen from four different angles in a closed hinge at maximum positive horizontal load.

C.1.2 Negative horizontal load

Finite element method analysis using computer aided software SolidWorks Simulation of a closed hinge when exposed to the maximum negative force before the part reaches its yield stress. The force is placed from the screw holes on the flat mounting section and directed inwards from the hinge.

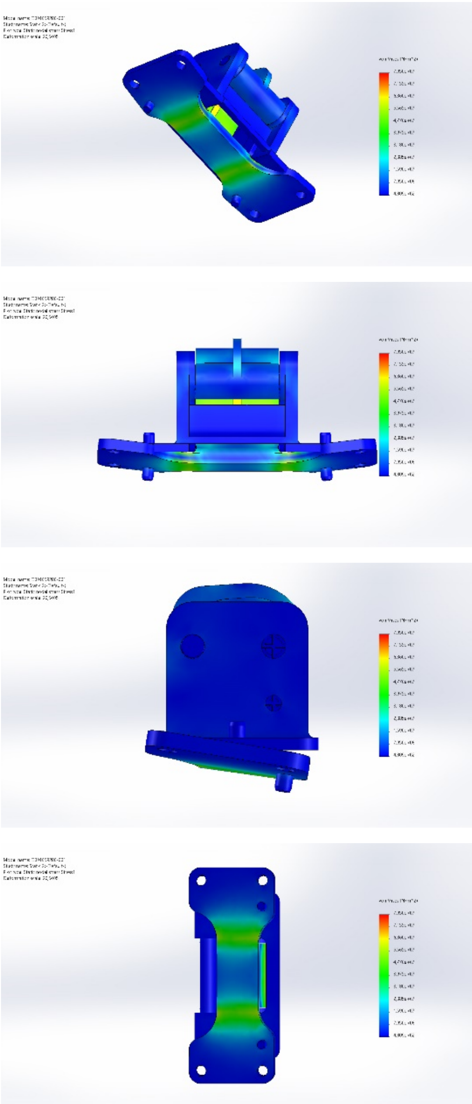


Figure 0.3 - Stress analysis seen from four different angles in a closed hinge at maximum negative horizontal load.

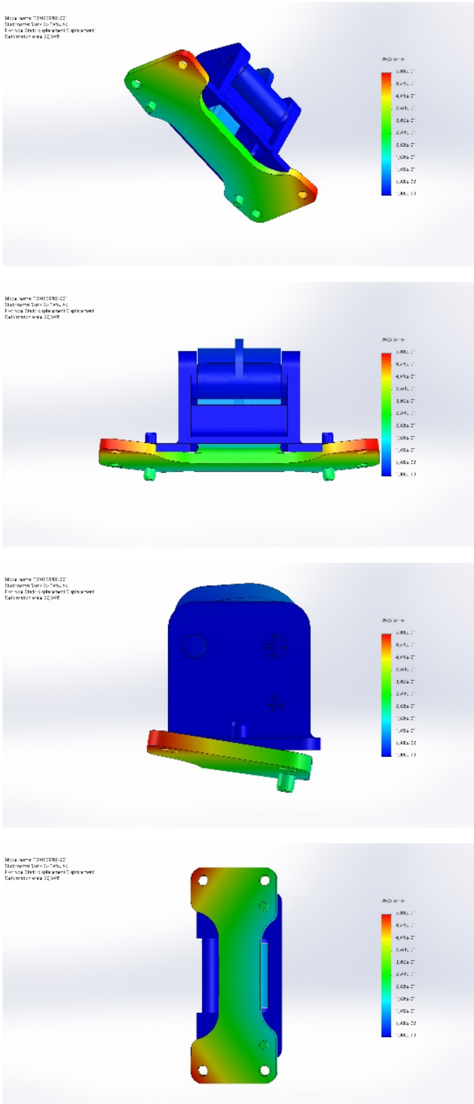


Figure 0.4 - Deformational analysis seen from four different angles in a closed hinge at maximum negative horizontal load.

C.1.3 Vertical load

Finite element method analysis using computer aided software SolidWorks Simulation of a closed hinge when exposed to the maximum force before the part reaches its yield stress. The force is placed from the screw holes on the flat mounting section and directed downwards from the hinge. Additionally, the mounting section is fixed in all directions except horizontal to mimic the movement of the hinges attached to a door.

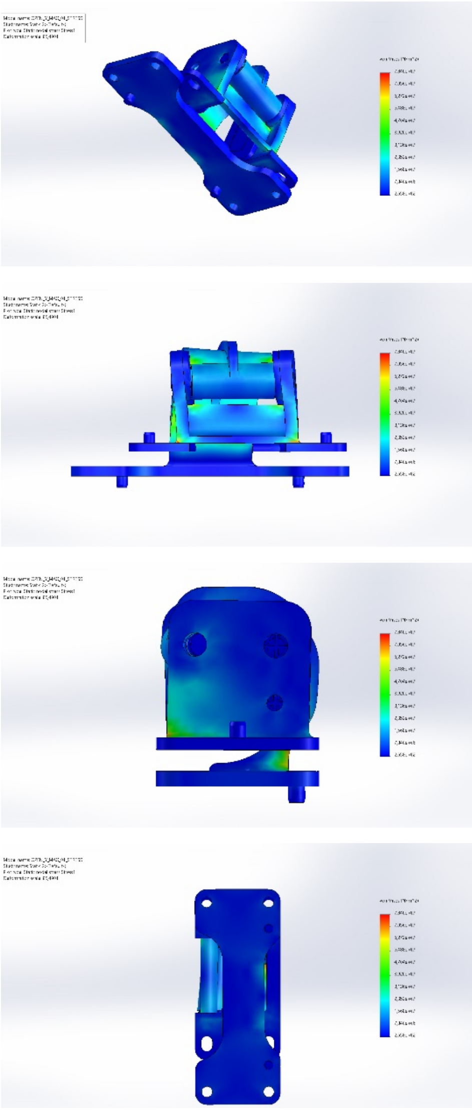


Figure 0.5 - Stress analysis seen from four different angles in a closed hinge at maximum vertical load.

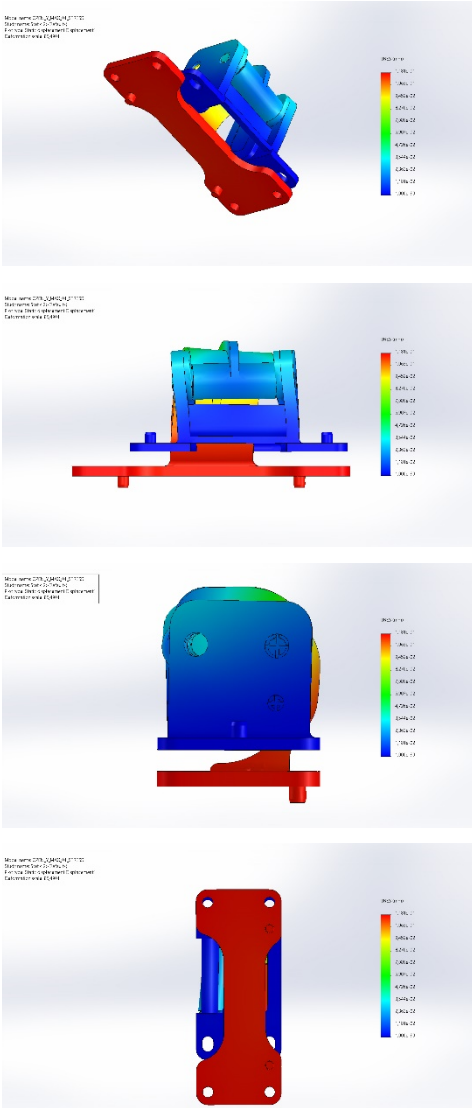


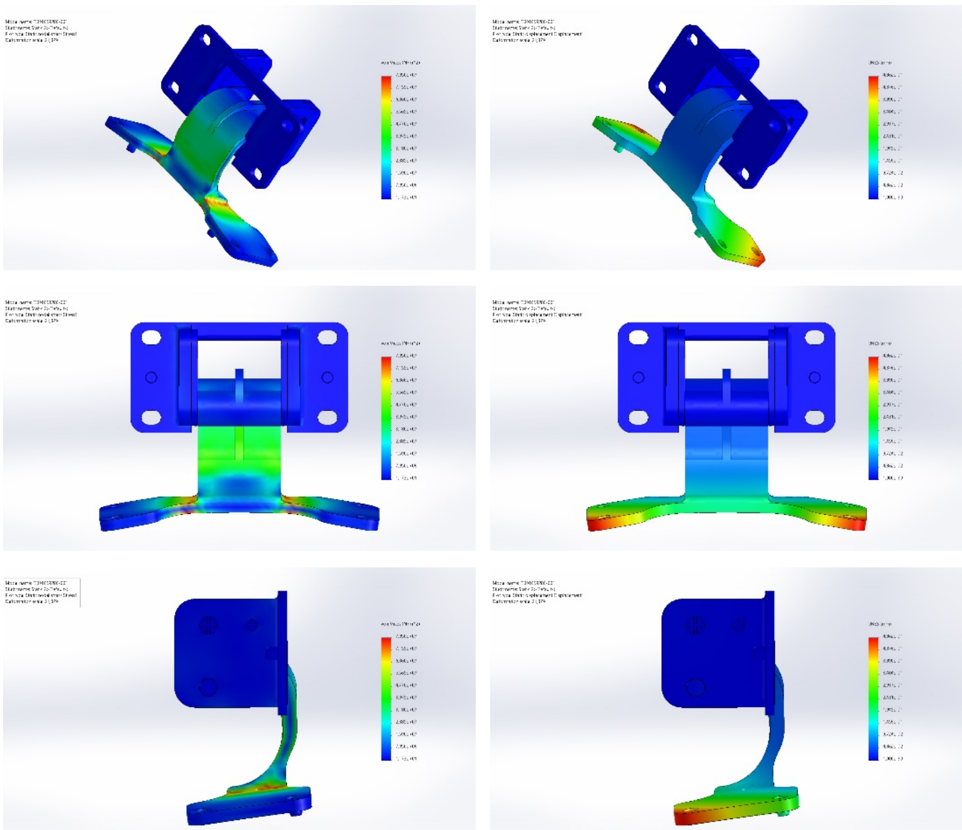
Figure 0.6 - Deformational analysis seen from four different angles in a closed hinge at maximum vertical load.

C.2 Open hinge

The simulations of the open hinge serves the purpose of analyzing the instance where the door is opened to 90°, with the purpose of simplifying the actual real maximum opening angle of 100°.

C.2.1 Positive horizontal load

Finite element method analysis using computer aided software SolidWorks Simulation of an open hinge when exposed to the maximum positive force before the part reaches its yield stress. The force is placed from the screw holes on the flat mounting section and directed outwards from the hinge.



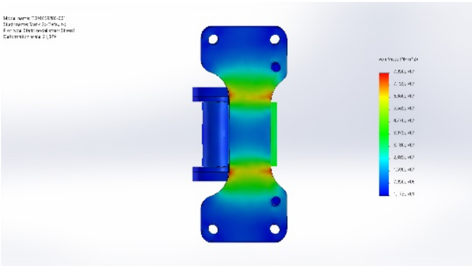


Figure 0.7 - Stress analysis seen from four different angles in an open hinge at maximum positive horizontal load.

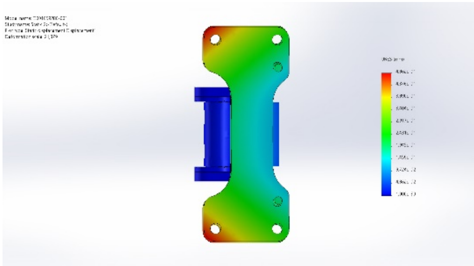
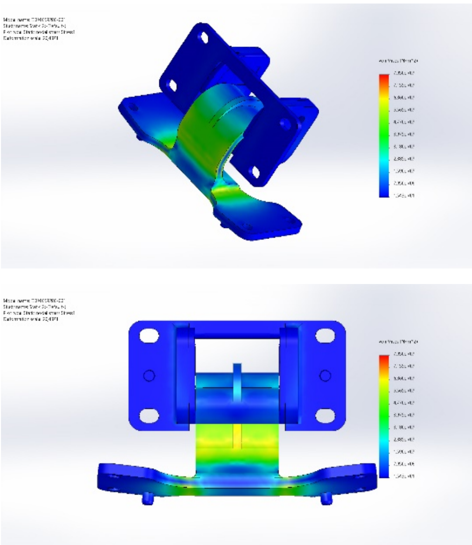
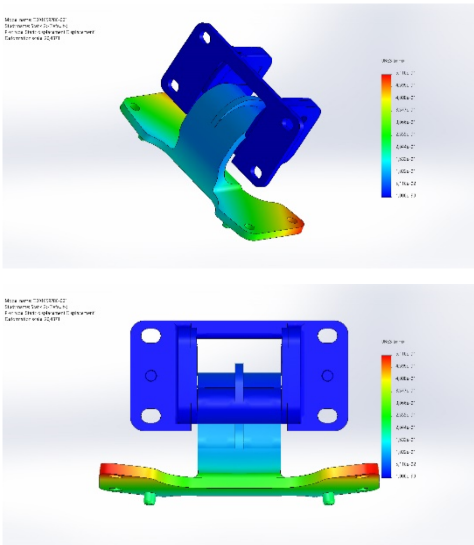


Figure 0.8 - Deformation analysis seen from four different angles in an open hinge at maximum positive horizontal load.

C.2.2 Negative horizontal load

Finite element method analysis using computer aided software SolidWorks Simulation of an open hinge when exposed to the maximum negative force before the part reaches its yield stress. The force is placed from the screw holes on the flat mounting section and directed inwards from the hinge.





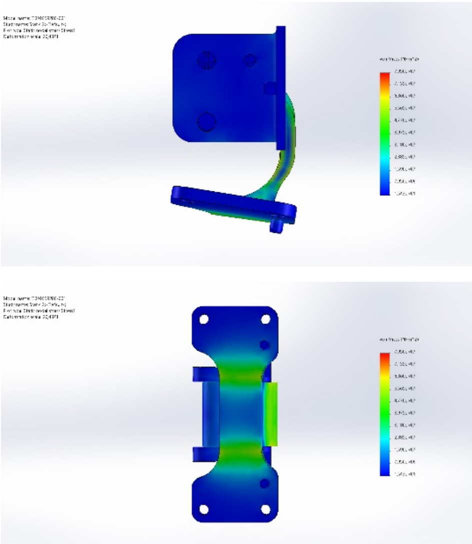


Figure 0.9 - Stress analysis seen from four different angles in an open hinge at maximum negative horizontal load.

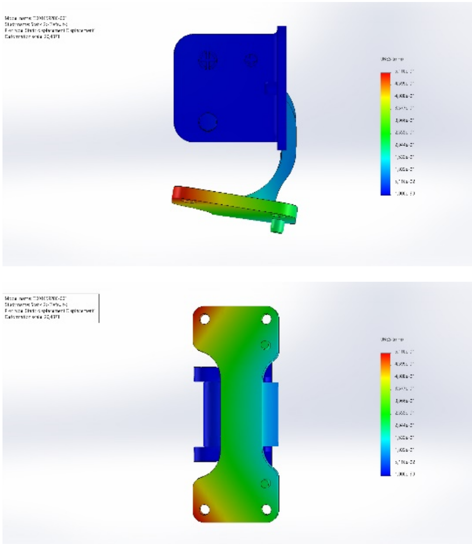
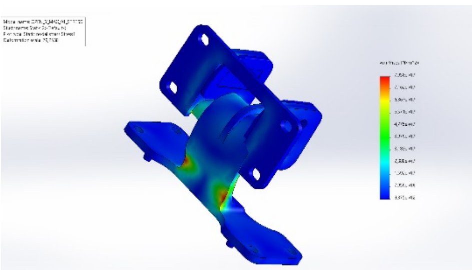
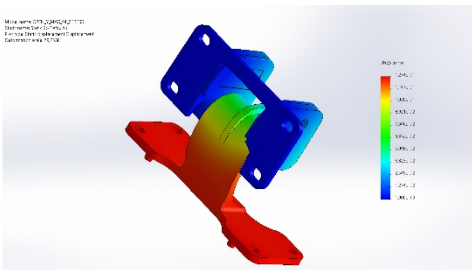


Figure 0.10 - Deformation analysis seen from four different angles in an open hinge at maximum positive horizontal load.

C.2.3 Vertical load

Finite element method analysis using computer aided software SolidWorks Simulation of an open hinge when exposed to the maximum force before the part reaches its yield stress. The force is placed from the screw holes on the flat mounting section and directed downwards from the hinge. Additionally, the mounting section is fixed in all directions except horizontal to mimic the movement of the hinges attached to a door.





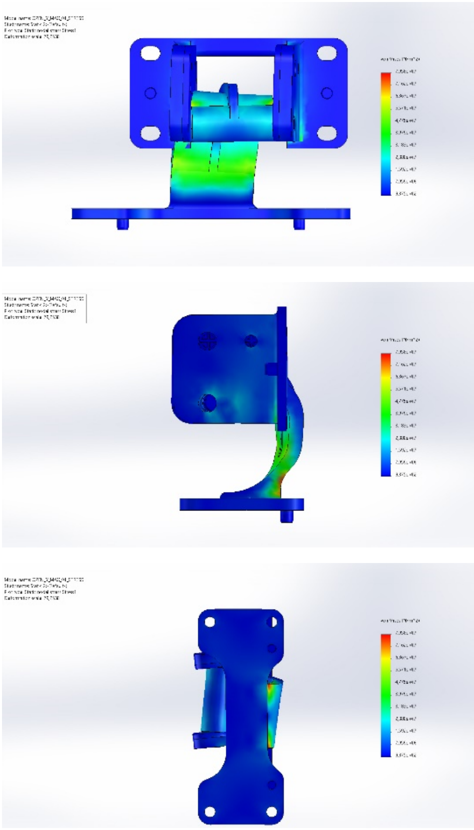


Figure 0.11 - Stress analysis seen from four different angles in an open hinge at maximum vertical load.

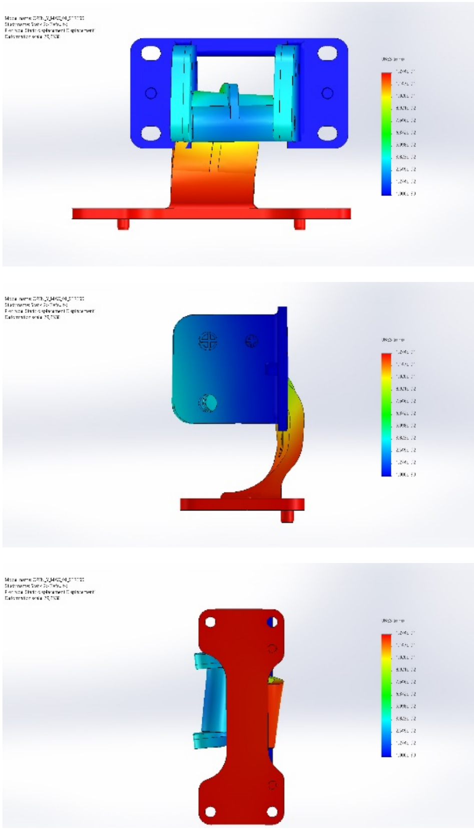


Figure 0.12 - Deformation analysis seen from four different angles in an open hinge at maximum vertical load.

C.2.4 Load normal to the door plane

Finite element method analysis using computer aided software SolidWorks Simulation of an open hinge when exposed to the maximum force before the part reaches its yield stress. The force is placed from the screw holes on the flat mounting section and directed inwards from the hinge, perpendicular from the door plane.

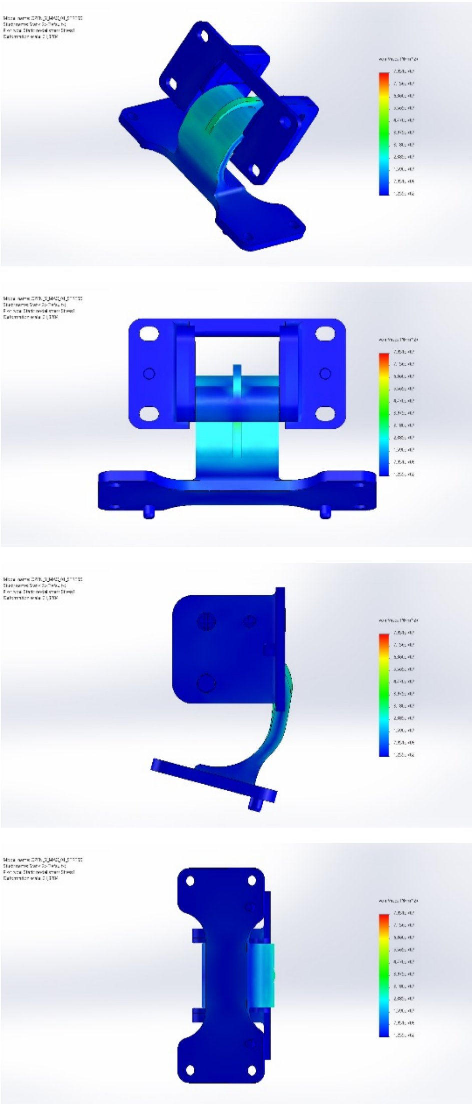


Figure 0.13 - Stress analysis seen from four different angles in an open hinge at maximum load normal to the door plane.

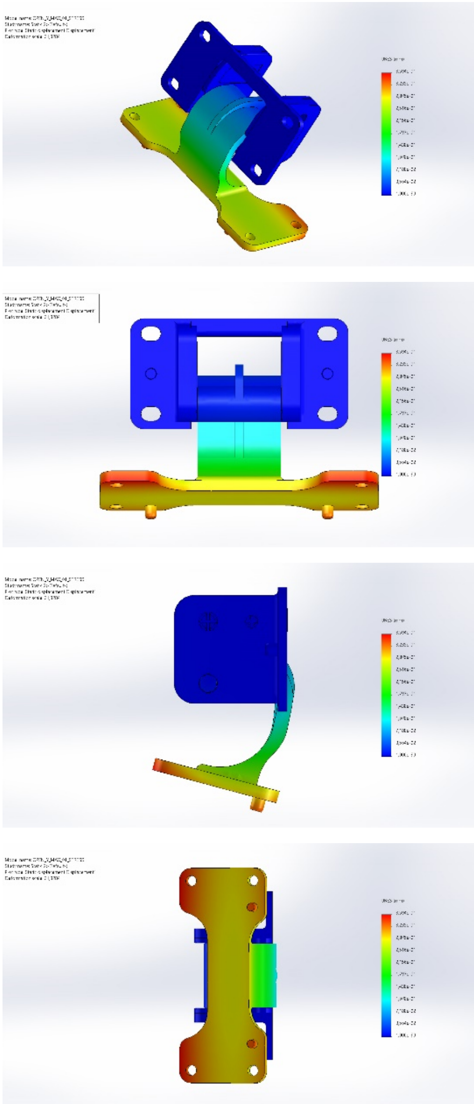


Figure 0.14 - Deformation analysis seen from four different angles in an open hinge at maximum load normal to the door plane.

Appendix D – Concept drawings

D.1 Drawings – OH1042P Passdoor

Appendix D.1 features a full list of components included in the OH1042P Passdoor, shown below in Table 0.2. The list consists of one assembly drawing, ten part-drawings and eight detail drawings of selected sections of the parts.

Table 0.2 - List of detailed drawings for an OH1042P Passdoor.

Drawing Name	*Comment*	*Featured in*
NEWPSD42-ASM01	Assembly drawing for the New PSD	
NEWPSD42-PRT01	Frame stile, outer handle side	
NEWPSD42-PRT02	Frame stile, outer hinge side	
NEWPSD42-PRT03	Frame stile, outer top	
NEWPSD42-PRT04	Threshold	
NEWPSD42-PRT05	Tube stile, handle side	
NEWPSD42-PRT06	Tube stile, hinge side	
NEWPSD42-PRT07	Tube stile, top	
NEWPSD42-PRT08	Frame stile, inner handle side	
NEWPSD42-PRT09	Frame stile, inner hinge side	
NEWPSD42-PRT10	Frame stile, inner top & bottom	
NEWPSD42-PRT11	Door panels	
NEWPSD42-DET01	Holes, outer frame stile mounting	*NEWPSD42-PRT01/02/03*
NEWPSD42-DET02	Mount lock plate, outer frame stile	*NEWPSD42-PRT01*
NEWPSD42-DET03	Hinge mount, outer frame stile	*NEWPSD42-PRT02*
NEWPSD42-DET04	Hinge holes, tube stile	*NEWPSD42-PRT06*

NEWPSD42-DET05	Lock box mount, inner frame stile	*NEWPSD42-PRT08*
NEWPSD42-DET06	Handle mount, inner frame stile	*NEWPSD42-PRT09*
NEWPSD42-DET07	Holes, inner frame stile mounting	*NEWPSD42-PRT08/09/10*
NEWPSD42-DET08	Hinge mount, inner frame stile	*NEWPSD42-PRT09*

D.2 Drawings – OH1082P Passdoor

Appendix D.2 features a full list of components included in the OH1082P Passdoor, shown below in Table 0.3. The list consists of one assembly drawing, ten part-drawings, eight detail drawings of selected sections of the parts, two modified part drawings and three modified assembly drawings, due to the changes needed to create parts for the new 82 mm thickness.

Table 0.3 - List of detailed drawings for an OH1082P Passdoor.

Drawing Name	***Comment***	***Featured in***
NEWPSD82-ASM01	Assembly drawing for the New PSD	
NEWPSD82-PRT01	Frame stile, outer handle side	
NEWPSD82-PRT02	Frame stile, outer hinge side	
NEWPSD82-PRT03	Frame stile, outer top	
NEWPSD82-PRT04	Threshold	
NEWPSD82-PRT05	Tube stile, handle side	
NEWPSD82-PRT06	Tube stile, hinge side	
NEWPSD82-PRT07	Tube stile, top	
NEWPSD82-PRT08	Frame stile, inner handle side	
NEWPSD82-PRT09	Frame stile, inner hinge side	
NEWPSD82-PRT10	Frame stile, inner top & bottom	
NEWPSD42-PRT11	Door panels	
NEWPSD82-DET01	Holes, outer frame stile mounting	*NEWPSD42-PRT01/02/03*

NEWPSD82-DET02	Mount lock plate, outer frame stile	*NEWPSD42-PRT01*
NEWPSD82-DET03	Hinge mount, outer frame stile	*NEWPSD42-PRT02*
NEWPSD82-DET04	Hinge holes, tube stile	*NEWPSD42-PRT06*
NEWPSD82-DET05	Lock box mount, inner frame stile	*NEWPSD42-PRT08*
NEWPSD82-DET06	Handle mount, inner frame stile	*NEWPSD42-PRT09*
NEWPSD82-DET07	Holes, inner frame stile mounting	*NEWPSD42-PRT08/09/10*
NEWPSD82-DET08	Hinge mount, inner frame stile	*NEWPSD42-PRT09*
D001037639-MOD82	Cold bridge, frame stile	*D001037636-MOD82*
D001075758-MOD82	Cold bridge, tube stile & threshold	*D001079847/75760-MOD82*
D001037636-MOD82	Frame stile, assembly	*NEWPSD82-PRT01/02/03/08/09/10*
D001079847-MOD82	Tube stile, assembly	*NEWPSD82-PRT05/06/07*
D001075760-MOD82	Threshold, assembly	*NEWPSD82-PRT04*

D.3 Drawing notes

Please note, that in this Appendix regarding the drawings of the New Passdoors, the eight detail drawings are similar between the OH1042P and OH1082P Passdoors. Differences are mainly clarification of location regarding the details on the parts, due to the modified thickness dimensions between the OH42P and OH1082P doors. Especially the drawings NEWPSD42-DET01 and NEWPSD42-DET07 are almost identical to the NEWPSD82-DET01 and NEWPSD82-DET07 drawings respectively, except in terms of naming and could be bundled together for reduction of the total number of files.

Appendix E – Time plan

Appendix E presents the time plan of the project, established in the initial weeks of the project.