THE DEVELOPMENT OF A FRAMELESS GLASS DOOR MADE FOR WHEEL LOADERS

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ABSTRACT
This thesis performed on master level covers an assignment given by the cab division at Volvo Construction Equipment (Eskilstuna, Sweden). The thesis has been carried out by Josefin Hult during the period 2014-01-23 to 2014-05-30 at Mälardalen University.

Volvo Construction Equipment manufactures products including wheel loaders, backhoe loaders and articulated haulers. The assignment involves developing the standard door for larger wheel loaders. The current door has a welded frame surrounding the glass that is considered outdated and not cost effective. Volvo Construction Equipment wishes that the door was made in glass in a greater extent. The aim of the assignment has been to generate concepts regarding a glass door that fulfills given requirements.

Three research questions have been stated and answered during the process.

The product development process has consisted of three phases: information gathering, concept development process and development of detailed concept. For example, field studies and benchmarking have been performed to gather information about competitors’ products and the manufacturing and assembling of the current door. Concepts for handrails, sealant and overall door design have been generated in an iterative process. All components of the door have been developed into a detailed concept during the last phase of the process. The process has resulted in a frameless glass door. The concept suggestion consists of; a tempered sheet of glass, a clip list (sealant) that covers the edges of the glass, two different handrails, inner and outer handles, a gas spring, components to attach handrails against the glass, a cover and a lock mechanism.

The major conclusion that is drawn is that it is fully possible to develop a door made in glass in a greater extent than the current door. Many competitors have machines where the door is made in glass in a large extent. This makes it believable that the glass door also will be perceived as timely and more modern and clear.

Recommendations have been developed if there is interest in further development. The recommendations include, among others, development of handrail and test of prototype to ensure that all requirements are fulfilled.

Figures are produced by the author if not stated otherwise.

Key words: Product development, Wheel Loader, Glass door, Glass, Door, Sealing, Sealant, Concept development, PDP, Construction Equipment
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Josefin Hult, Eskilstuna (Sweden)
2014-05-30
**Cabin frame** – The beams that forms the frame of the cabin’s doorway.

**CAD** – Computer Aided Design. A computer software for designing i.e. products.

**CAST** – Common Architecture Shared Technology. A handbook for Volvo Construction Equipment that describes e.g. interfaces between parts.

**CTS** – Common Technology Solution. A manual where standards and internal guidelines from Volvo Construction Equipment are stated that are used when developing products.

**DFMA** – Design for Manufacture and Assembly. A product development tool that intends to facilitate manufacturing and assembling.

**EPDM** – Rubber material often used for sealing.

**IDEO** – An innovation firm whose product development process has been used as support during the project.

**PD** – Product Development.

**PDP** – Product Development Process.

**PD-tool** – Product Development tool.

**Pugh’s method** – An evaluation method of products and concepts.

**RPS** – Reference Point System. A Volvo system made to facilitate manufacturing.

**Standard door** – The current door for larger wheel loaders.

**SVID** – An industrial design foundation whose product development process has been used as support during the project.

**Volvo CE** – Volvo Construction Equipment.

**WLO** – Wheel Loader.
## CONTENTS

1.0 Introduction .................................................................................................................. 1

1.1 Problem formulation....................................................................................................... 1

1.2 Aim and research questions.......................................................................................... 1

   1.2.1 Aim ......................................................................................................................... 1

   1.2.2 Research questions ................................................................................................. 1

1.3 Delimitations .................................................................................................................. 2

2. Research methodology ................................................................................................... 3

   2.1 Phase 1 - Information gathering ................................................................................ 3

      2.1.1 Databases .............................................................................................................. 3

      2.1.2 Questionnaire ........................................................................................................ 3

      2.1.3 Forum search .......................................................................................................... 4

      2.1.4 Field studies .......................................................................................................... 4

   2.2 Phase 2 - Concept development process ..................................................................... 4

   2.3 Phase 3 - Development of the detailed concept ....................................................... 5

      2.3.1 Summarization of the PDP .................................................................................. 5

   2.4 Reliability and validation ........................................................................................... 5

3. Theoretical framework .................................................................................................... 6

   3.1 Volvo CE .................................................................................................................... 6

   3.2 What is a WLO? ........................................................................................................... 6

   3.3 Glass ............................................................................................................................ 6

      3.3.1 Pilkington .............................................................................................................. 7

      3.3.2 To process glass .................................................................................................... 7

   3.4 Sealing .......................................................................................................................... 7

   3.5 Standards ..................................................................................................................... 7

   3.6 Volvo’s systems .......................................................................................................... 8

      3.6.1 RPS ....................................................................................................................... 8

      3.6.2 CAST .................................................................................................................... 8

      3.6.3 CTS ....................................................................................................................... 8

   3.7 DFMA .......................................................................................................................... 8

   3.8 Pugh’s method ............................................................................................................. 8

   3.9 Ergonomics .................................................................................................................. 8

   3.10 Product development methodologies ....................................................................... 9

      3.10.1 Volvo PDP ............................................................................................................ 9

      3.10.2 IDEO .................................................................................................................... 9

      3.10.3 The Mechanical Design Process ....................................................................... 9
5.1.2 Handles .................................................................................................................. 34
5.1.3 Hinges ..................................................................................................................... 35
5.1.4 Handrails ............................................................................................................... 35
5.1.5 Handrail holders .................................................................................................... 35
5.1.6 Lock mechanism and its holder ............................................................................. 36
5.1.7 Gas spring and its holder ....................................................................................... 36
5.1.8 Sealant .................................................................................................................... 36
5.1.9 Rubber protection for components ........................................................................ 36
5.1.10 Cover .................................................................................................................... 37
5.1.11 Fasteners .............................................................................................................. 37
5.1.12 RPS ....................................................................................................................... 37
5.2 Prototype .................................................................................................................... 37
5.3 Assumed strength ..................................................................................................... 37
5.4 Estimated cost ........................................................................................................... 37
6. Analysis ......................................................................................................................... 38
6.1 Phase 1 - Information gathering ............................................................................... 38
  6.1.1 Field studies ......................................................................................................... 38
  6.1.2 Forum search ........................................................................................................ 38
  6.1.3 Ergonomic test ...................................................................................................... 38
  6.1.4 Questionnaire ...................................................................................................... 38
  6.1.5 RQ3: Which functions does the wlo door need to fulfill? ..................................... 39
  6.1.6 RQ2: What are the arguments for designing a wlo door in glass without a frame? ................................................................. 39
6.2 Phase 2 - Concept development process .................................................................. 40
6.3 Phase 3 - Development of detailed concept ............................................................ 40
  6.3.1 RQ 1: How can the wlo door be designed in order to ensure that strength, function and safety requirements are met? ......................... 40
6.4 Validation against requirement specification .......................................................... 42
  6.4.1 Summarization of the fulfilled requirements ......................................................... 44
7. Conclusions and recommendations ............................................................................ 45
  7.1 Conclusions .............................................................................................................. 45
    7.1.1. Result ............................................................................................................... 45
    7.1.2. Method ............................................................................................................ 45
    7.1.3 Process ............................................................................................................. 45
7.2 Recommendations ..................................................................................................... 46
    7.2.1 Glass .................................................................................................................. 46
7.2.2 Vertical handrail ................................................................. 46
7.2.3 Sealant .............................................................................. 46
7.2.4 Cover ............................................................................... 46
7.2.5 Gas spring holder ............................................................. 46
7.2.6 Prototype test ................................................................. 46
7.2.7 Cost reduction ................................................................. 46
7.2.8 Glass door that is perceived as safe .................................. 46

8. References ............................................................................ 47
8.1 Literature sources .............................................................. 47
8.2 Internet sources .................................................................. 47
8.3 Verbal sources ................................................................... 50

9. Appendices .......................................................................... 51
# TABLE OF FIGURES

<table>
<thead>
<tr>
<th>Figure No.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The standard door</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>The PDP</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>WLO L250G ©Volvo CE</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Shattered tempered glass ©Universal windows</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Sealing ©DAFA</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>Volvo’s PDP ©Volvo (2014)</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>The mechanical design process ©Ullman (2010, p.82)</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>A step in the door manufacturing</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>Volvo Articulated Hauler ©Volvo</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>The two handrails seen from inside the standard door</td>
<td>12</td>
</tr>
<tr>
<td>11</td>
<td>Ergonomic test</td>
<td>13</td>
</tr>
<tr>
<td>12</td>
<td>The standard door seen from inside</td>
<td>14</td>
</tr>
<tr>
<td>13</td>
<td>A CAD illustration of the standard door</td>
<td>14</td>
</tr>
<tr>
<td>14</td>
<td>Section view of the frame’s profile</td>
<td>15</td>
</tr>
<tr>
<td>15</td>
<td>The gas spring</td>
<td>15</td>
</tr>
<tr>
<td>16</td>
<td>The current upper hinge</td>
<td>15</td>
</tr>
<tr>
<td>17</td>
<td>The outer and inner handle</td>
<td>15</td>
</tr>
<tr>
<td>18</td>
<td>The handrails</td>
<td>15</td>
</tr>
<tr>
<td>19</td>
<td>L105 Door</td>
<td>16</td>
</tr>
<tr>
<td>20</td>
<td>WLO L25F ©Volvo</td>
<td>16</td>
</tr>
<tr>
<td>21</td>
<td>Sealant</td>
<td>16</td>
</tr>
<tr>
<td>22</td>
<td>Hinges for L20/50</td>
<td>16</td>
</tr>
<tr>
<td>23</td>
<td>©Fendt, Claas, Valtra</td>
<td>17</td>
</tr>
<tr>
<td>24</td>
<td>©Lännen lundberg, ©Lännen</td>
<td>17</td>
</tr>
<tr>
<td>25</td>
<td>©Huddig, New Holland</td>
<td>17</td>
</tr>
<tr>
<td>26</td>
<td>From top left: ©JCB, ©Liu Gong. From bottom left: ©CAT, ©Gehl</td>
<td>18</td>
</tr>
<tr>
<td>27</td>
<td>©John Deere, ©Bosal Sekura</td>
<td>18</td>
</tr>
<tr>
<td>28</td>
<td>Cost for standard door</td>
<td>20</td>
</tr>
<tr>
<td>29</td>
<td>Evaluated products</td>
<td>23</td>
</tr>
<tr>
<td>30</td>
<td>Compact Mobile Crane AC40 ©Bosal Sekura</td>
<td>23</td>
</tr>
<tr>
<td>31</td>
<td>Lännen Lundberg 4200LS ©Lännen</td>
<td>23</td>
</tr>
<tr>
<td>32</td>
<td>New Holland T5 Electro Command Tractor ©New Holland</td>
<td>23</td>
</tr>
<tr>
<td>33</td>
<td>Claas Axos 340–310 ©Claas</td>
<td>23</td>
</tr>
<tr>
<td>34</td>
<td>Volvo WLO L20F ©Volvo</td>
<td>23</td>
</tr>
<tr>
<td>35</td>
<td>Concept 1 and 6 from step (1)</td>
<td>25</td>
</tr>
<tr>
<td>36</td>
<td>Evaluation of sealant suggestions in Pugh’s matrix</td>
<td>26</td>
</tr>
<tr>
<td>37</td>
<td>Sealant concept 2.1</td>
<td>27</td>
</tr>
<tr>
<td>38</td>
<td>Sealant concept 2.3</td>
<td>27</td>
</tr>
<tr>
<td>39</td>
<td>Sealant concept 2.4</td>
<td>27</td>
</tr>
<tr>
<td>40</td>
<td>Selanat concept 2.5</td>
<td>27</td>
</tr>
<tr>
<td>41</td>
<td>Sealant concept 2.6</td>
<td>27</td>
</tr>
<tr>
<td>42</td>
<td>Combined concept 1</td>
<td>28</td>
</tr>
<tr>
<td>43</td>
<td>Combined concept 2 and 3</td>
<td>28</td>
</tr>
<tr>
<td>44</td>
<td>Combined concept 4</td>
<td>28</td>
</tr>
<tr>
<td>45</td>
<td>Combined concept 5</td>
<td>29</td>
</tr>
<tr>
<td>46</td>
<td>Combined concept 5, lower part of vertical handrail</td>
<td>29</td>
</tr>
</tbody>
</table>
1.0 INTRODUCTION
This report summarizes the thesis work at master level that has been carried out by Josefin Hult at Mälardalen University in collaboration with Volvo Construction Equipment (hereinafter named Volvo CE) at the cab division in Eskilstuna (Sweden) during 2014-01-20 to 2014-05-30.

1.1 PROBLEM FORMULATION
The assignment that was given was to redesign the standard door for the larger wheel loaders (WLOs) since the door is not considered cost effective or modern looking. The standard door consists of the main parts that are a steel frame, a tempered sheet of glass, inner and outer handles that connects to a lock, handrails and a gas spring for a safe opening and closing of the door, see figure 1.

The assignment has been stated as follows: To redesign or if possible remove the steel frame that surrounds the glass in the current door (standard door) so that the door is made in glass in a greater extent than today. This should be done without risking safety aspects as well as strength and function requirements.

1.2 AIM AND RESEARCH QUESTIONS
The aim of the assignment and the research questions (RQ) that this thesis is built upon is stated below.

1.2.1 AIM
The purpose of the assignment is to develop the standard door. This should be performed by generating concepts for the door where it is designed in glass in a larger extent than the current solution, and in the meantime design the door in a cost effective way. The concept shall fulfill the same functions and requirements as the solution today.

1.2.2 RESEARCH QUESTIONS
The research questions (RQs) are divided into one main question and two sub questions. The sub questions are intended to help answer the main question of this thesis.

Main question
RQ1. How can the WLO door be designed in order to ensure that strength, function and safety requirements are met?

Sub questions
RQ2. What are the arguments for designing a WLO door in glass without a frame?
RQ3. Which functions does the WLO door need to fulfill?
1.3 DELIMITATIONS
In accordance with Volvo CE, the generated concepts should be based on the following aspects:

- The original parts for door handles, lock mechanism and gas spring should be used.
- The door should express a “modern feeling”.
- There should be an inner handle or handrail that acts as an elongation of the entry. Ergonomics needs to be investigated in this respect.
- The door needs to fulfill the sealing requirements stated in the internal document CTS “Preferred solutions of doors”.
- To provide a safe entering and exiting there needs to be a three-point grip, which means that the operator always shall have support for two feet and one hand or two hands and one foot.

The work will mostly be performed at Volvo CE Eskilstuna but resources will when needed be used from Mälardalen University Eskilstuna during the period 2014-01-20 to 2014-05-30 with in average 40h per week. Time is the biggest constraint. How the different components are being made or how they should be manufactured will, therefore, not be covered. There will also not be any room to find the cost for the concept suggestions, assumptions will instead have to be made. Only if time permits will simulations and calculations be performed, otherwise the concepts will be evaluated against competitors’ products in order to ensure a satisfying quality. If the time and possibility exists, a prototype will be made to test function and design.

The tasks that are considered as prioritized are:

- Investigate existing door solutions in aspect to function and design, both products from Volvo CE and competitors.
- Collect information about what functions and requirement that the door needs to fulfill.
- Investigate what impressions regarding quality and opinions that exist about agricultural machines where the doors and cabins often are designed in glass in a large extent.
- Generate more concepts rather than one in detail.
2. RESEARCH METHODOLOGY

A broader study has been conducted with quantitative secondary and primary data to answer the RQs. The data has been gathered by using the Volvo CTS database, databases offered at the Mälardalen University library and finally Internet sources to complement the printed sources (Booth, Colomb and Williams, 2004, p.89). The primary data has been gathered during field studies of both agricultural machinery and construction equipment, which are described more in more detail below. The project has been divided into three larger phases:

- Phase 1: Information gathering
- Phase 2: Concept development process
- Phase 3: Development of the detailed concept

The product development processes (PDPs) by: Ullman (2010), SVID and IDEO (described in section 3.10) have been used as support and a way of structuring the work during the project. Phase 1 is intended to answer the two sub questions (RQ2 and 3) and give deeper understanding of the core of the assignment in order to answer the main question (RQ1) during phase 2 and 3.

2.1 PHASE 1 - INFORMATION GATHERING

The different methods for information gathering are outlined below.

2.1.1 DATABASES

The databases Discovery and Google Scholar (Bell, 2006, p.93, p.95; Horne, 2004), provided by the library at Mälardalen University, were used to perform a literature study in order to find information about glass, sealant, (glass) doors and how to experience a product as safe. A database search is proposed by Booth, Colomb and Williams (2004, p.84) to be the first step when gathering information. Search words have included “glass”, “glass door”, “sealing”, “weather strip”, “sealing door”, “seal and door” “semantic design feeling security”, and “product development feeling of safety”. These have been chosen after the advice from Bell (2006, p.93) that refers to Horne (2004) to use specific search words in order to get concrete answers. Focus has primarily been to choose sources that are as new as possible to hold relevance (Booth, Colomb and Williams, 2004, p.89). Unfortunately, no usable information has been found during the database searches given the scope and time limit of this project. The Google search engine has been the primary database when searching for products from competitors, existing component solutions and similar. This is a method that should not be underestimated according to Bell (2006, p.93) that refers to Horne (2004).

2.1.2 QUESTIONNAIRE

Quantitative information has been gathered by sending out a questionnaire to seven retailers of different agricultural and construction equipment. The main purpose of the questionnaire was not to confirm assumptions but rather to gather as much information as possible about function and design of doors that competitors use and opinions about them. The questionnaire was built on single respond and open questions that according to Bell (2006, p.138) is the type of questions that should be used when the respondents should be able to express their opinions. By having this combination of questions, a broader view on information and opinions about the door could be given. The questions were made with the thought of not being leading or judgmental (Bell, 2006, p.144). Unfortunately, even though reminders were sent out only two responses were received thus weakening the conclusion (Bell, 2006, pp.151; Moser & Kalton, 1971, p. 267-268).
2.1.3 FORUM SEARCH
Quantitative information has also been gathered by searching in forums, in particular at the forum Maskinisten (The Machinist, authors’ translation). There is a great quantity of different agricultural and construction equipment discussed in this forum (Maskinisten, 2012). By focusing on this forum the opinion has been that if the information is not found here then it is unlikely to be found anywhere else given the time limit and project scope. When searching on the forum it has been considered to be extra important to have a critical mindset and questioning if the sources are reliable (Booth, Colomb and Williams, 2004, p.83). When reading posts and comments it became clear that the majority had the same general opinion, a conclusion was therefore made that the sources could be considered reliable.

2.1.4 FIELD STUDIES
Three different field studies have been performed to gain a greater understanding of both machines from competitors and products offered by Volvo CE today. This was done in order to give the author of this report her own view of the products. The field studies have contributed with primary data that complements the secondary data (Bell, 2006, p.187). The field studies have been unstructured types of observations since there was a clear purpose of the observation (Bell, 2006, p.188). However, since the objects that have been observed have been mostly machines there has not been a real method for observation, rather trying to investigate design and function of the different doors and their components.

- Volvo CE Hallsberg (Sweden)
The production and assembling of the standard door were studied by observations in the beginning of the project in order to get a starting point of knowledge. Emphases was on the parts that take the most time to produce and are experienced as difficult in the production so that when generating concepts these parts would be avoided.

- Lantmännen Eskilstuna
Lantmännen is a retailer of agricultural machines (Lantmännen, 2014a). A visit to them was made together with the industrial supervisor at Volvo CE with the hope of being able to look closer at the design of the doors. However, the visit was spontaneous and, therefore, unfortunately unplanned.

- Volvo Customer Center Eskilstuna
In connection with a machine show at Volvo Customer Center an opportunity to ride along in an articulated hauler was given. During the visit, focus was on how the entry was designed, the general look and impression of the door and how people used the door when they entered and exited the cabin.

2.2 PHASE 2 - CONCEPT DEVELOPMENT PROCESS
The process has been highly iterative with multiple cycles of generated ideas combined with integration of phase 1 whenever more information was needed in order to develop ideas. This phase has had the highest focus and has taken the most time in line with the methodology by IDEO (see section 3.10.2). As support, different product development tools (PD-tools) were used in order to make sure that no important requirements or functions were forgotten.
2.3 PHASE 3 - DEVELOPMENT OF THE DETAILED CONCEPT
During this phase, priority has been on developing the concept that has been considered the one with the most potential from phase 2 and that answers best to the specified requirements. In order to make sure that the concept does answer to the requirements, discussions have been held with Volvo CE employees several times during the project. The concept development has been done with the help of CAD, which has facilitated finding design opportunities. In the end of the project, the first step towards a prototype was made that aims to test the design and functions of the detailed concept.

2.3.1 SUMMARIZATION OF THE PDP
The process can be seen as an illustration in figure 2 to provide an overall view of the project. This structure has been followed during the project and is the same as this report is built upon.

![Figure 2: The PDP](image)

2.4 Reliability and validation
To assess the quality of the work in a project there are two terms, reliability and validation, that expresses how quality can be measured. According to Bell (2006, p.117) reliability is a measurement in what extent an approach generates the same results at different moments but at the same circumstances. The reliability can depending on situation, be measured by different methods. For example, questions can be asked with different formulations but with the same meaning or a test-retest (performing the same test at a different time) can be performed to test if the result is coherent. Validation is, according to Bell (2006, p.117), a measure of how well a question measures what it is intended to measure or describe.

In this project, the reliability and validity can be seen as how likely it is that the same result would be given if the project would be run again. The reliability and validity have been confirmed by using PD-tools for objective evaluations and continuous discussions have been held with Volvo CE employees to create a result that is seen as fulfilling the requirements. With this said, a generated idea is built on knowledge, experience and fantasy which means that it is fully possible that there are other ideas that can be thought of and that would function.
3. THEORETICAL FRAMEWORK
The theoretical framework that has been used during the project is outlined in this chapter.

3.1 VOLVO CE
Volvo CE is a part of the Volvo Group and is among the leading manufactures in their field. Their range of products includes, among others: wheel loaders, articulated haulers, backhoe loaders, pavers and compactors. The products are used in different fields, from general construction to forestry and demolition. (Volvo CE, 2014a)

3.2 WHAT IS A WLO?
A WLO stands for a Wheel Loader. It is a construction machine, which comes in different sizes depending on its intended use. A smaller WLO is often referred to as a compact WLO whereas a larger WLO is simply a WLO, see figure 3. A WLO can be used for handling gravel and similar materials. The environment that a WLO operates in is often rough in the meaning that it is used in more or less all kinds of weather, the surroundings are dirty and the driver is often working long hours. (Volvo CE, 2014b)

3.3 GLASS
Glass is not just a material with one function. Depending on how it is manufactured, glass is made with different mechanical properties and can be used for different purposes. The purposes’ include pure design objects, windows, façades and much more. One could say that the sky is the limit. (Pilkington, 2014)

Glass is usually divided into three different groups:

- Float
- Hardened (toughened or tempered)
- Laminated

Float glass is glass in the first step that has not been altered. This glass is easy to break and when breakage occur sharp glass fragments are formed. Tempered or toughened glass is as it sounds, tougher and stronger to withstand forces. This is a sort of safety glass and if breakage occurs the glass will shatter in many small pieces that are not sharp and therefore does not make damage or hurt people, see figure 4.

When making cutouts in tempered glass, the cutouts must be made before the glass is tempered otherwise it will shatter into pieces. Laminated glass has a small plastic film in between sheets of glass. This makes it harder to break the glass. If breakage does occur, the plastic film collects the glass shatter, which means that there will not be any glass shatter capable of hurting a person. (Hägglöf, 2011)
3.3.1 **Pilkington**
Pilkington is considered one of the larger companies in the field of glass (Pilkington, 2014a). Based on a conversation with a salesperson at Martin G Andersson (a company in the glass industry) it is the recommendations from Pilkington that have been followed in this project.

3.3.2 **To process glass**
When making holes in a sheet of glass there are a couple of things to keep in mind. The following guideline is taken from Pilkington (2014b) (*translation by the author of this thesis*) and has been followed when setting the dimensions for the glass sheet.

“**Holes and cutouts in glass**
The distance from edge to hole with less than 50mm diameter shall be at least 1.5 times the glass thickness, and if the glass is 8mm or more it shall be at least 2 times the thickness. At corners shall the distance in the opposite direction be at least 4 times the glass thickness. If the hole is more than 50mm in diameter, or rectangular, the distance must exceed 0.5 times the hole diameter and the width of the hole. The distance between holes shall be 0.5 times the largest hole diameter, or at least 2-5 times the thickness of the glass. A circular hole must never be larger than a third of the width of the glass. In a rectangular hole can the hole width be maximum a third of the height of the glass sheet. Cutouts from the edge can be maximum 150mm deep and cannot be closer to a corner than 100mm. The radii to a predrilling hole in rectangular cutouts shall be at least equal to the thickness of the glass and never less than 10mm.” (Pilkington, 2014)

3.4 **Sealing**
A sealant is used when a part, for example, needs to be secured from particles and/or fluids, lower vibrations and keep air pressure. A sealant can consist of different kind of materials but is usually made in some kind of rubber. EPDM is a common alternative since it can be altered to sustain weather, heat, sunlight and more (Takcentrum, 2014). The profile of the sealant depends on where or what needs to be sealed. Depending on where the sealant needs to be applied different alternatives can be used, depending on what the environment looks like and what materials the sealant will attach to. For example, the sealant can be attached with adhesives, tape, nails or simply by being hammered into place. The sealants tooth like parts as seen in figure 5 attaches the sealant without use of adhesives or similar.

3.5 **Standards**
The following standards have been taken into account in this project:

- **BS EN ISO 2867:2011 Dimensions of handrails and handholds.** (Internal document, Volvo CE)
  The standard state, among others, distances that is valid between handles/handrails and mounting surfaces.

- **SS-EN 572 Mechanical properties in glass** (Pilkington, 2014c)

- **Standards included in the document “CAST For Doors Preferred solutions” and the CTS guidelines.** (Internal document, Volvo CE)
  The document states, among others:
  
  "Confidential information"
3.6 VOLVO’S SYSTEMS
Volvo has different systems and standards that are used to ease developing and manufacturing of their products.

3.6.1 RPS
RPS stands for Reference Point System and is used in order to establish reference points from CAD onto a physical object and assist to facilitate manufacturing.

(Sundh & Decoo, Cast for Cabs Handbook)

3.6.2 CAST
CAST stands for Common Architecture Shared Technology and can be equated with DFMA (described below). CAST involves the following:
CA: Takes a product’s architecture into account. This involves, for example, how the components are structured and related to each other.
ST: Guidelines that are used in order to share the knowledge about best practices.

/Internal document CAST For Doors Preferred solutions, 2011

3.6.3 CTS
In order to simplify future work, what can be described as a manual is developed. This manual is called a CTS that stands for Common Technology Solution and supports the work when, in this case, new doors are being developed. The manual includes information about standards and solutions that should be used.

/Internal document CAST For Doors Preferred solutions, 2011

3.7 DFMA
DFMA stands for Design for Manufacturing and Assembling. This PD-tool helps product developers to design a product that facilitates manufacturing and assembling. It consists of various things including where screws should be placed, error proofing, how parts relate to each other and if parts can be integrated. (Boothroyd, Dewhurst and Knight, 2011, p.8-15; Ulrich and Eppinger, p.224-227, 2008)

3.8 PUGH’S METHOD
Pugh’s method, also called the decision-matrix method, can be used when evaluating existing products and wanting to narrow down number of concepts. This PD-tool allows a more objective evaluation because the concepts are evaluated against the requirement specification and not against feelings and thoughts one can have about an idea. (Ulrich and Eppinger, 2008, pp.130; Ullman, 2010, p.221-224)

3.9 ERGONOMICS
A good working environment for a person that uses WLOs includes among other things that the handles and handrails have a good design and that they are placed in such a way that it is easy to reach and use them. Andersson and Nedergård (2004, p.11) refers to Kroemer and Grandjean (2000) who says, “Controls should be positioned between elbow and shoulder height so they are easy for the operator to reach”. To use a handle or handrail in an ergonomic way means that the hand should not have to be raised above shoulder level (Hägg, Ericson and Odenrik, 2008, p.176).
3.10 PRODUCT DEVELOPMENT METHODOLOGIES

There are different methodologies that can be used in a product development process (PDP). In this project, the methodologies by Volvo, IDEO, Ullman (2010) and SVID have together acted as inspiration, support and provided structure.

3.10.1 Volvo PDP

As seen in figure 6, Volvo has a global PDP (the GDP) that consists of six stages. This project can be considered to concern stages one and two where scope of the project is set, requirements are found and concepts are generated and evaluated, where for instance market research is taken into consideration. (Volvo, 2014)

3.10.2 IDEO

IDEO is a design firm that focuses on helping companies to create innovations in order to grow. Their approach is human-centered, which means that the human (the user) is in focus when developing i.e. a new product. Hopefully, by dedicating a larger amount of time to researching a greater understanding of the problem a better solution will arise. (IDEO, 2014)

3.10.3 The Mechanical Design Process

The PDP by Ullman (2010) consists just like Volvo’s PDP of six general phases, see figure 7. This project can be considered to be part of phases one to five where focus has been on phase four. The first phase involves finding the needs that during the later phases should be fulfilled. Phase two aims to plan the project; phase three involves benchmarking and finding customers’ requirements and phase four focuses on generating and evaluating concepts. In phase five, the concept further develops into a product and is evaluated against aspects like DFx (Design for x, where x can be i.e. assembling, manufacturing, environment), costs, production, and performance and robustness. (Ullman, 2010, p.81-90)

3.10.4 SVID

SVID stands for Stiftelsen Svensk Industridesign (The Foundation Swedish Industrial Design, author’s translation). According to SVID the process of developing products is beginning with user studies followed by concepts and visualization. The concepts will then be evaluated and one will be chosen to continue with. That concept will be adjusted and when it is considered to be done the change/new product will be implemented into production. When that is completed, a follow-up will be made in order to find ways to improve next time. This can be seen as quite strict where the process is not highly iterative. (SVID, 2014)
4. APPLIED METHODOLOGY
The three phases of this project are outlined in this chapter.

4.1 PHASE 1 - INFORMATION-GATHERING
The information-gathering phase has consisted of the following parts:

- Benchmarking
- Ergonomic test
- Costs
- Requirement specification
- Functional analysis
- Evaluation of existing products (competitors and internal)

The information that these parts have provided has helped answer RQ2 and RQ3 and is described below.

4.1.1 BENCHMARKING
The benchmarking has consisted of several parts in accordance with the earlier described method. To start with, a market analysis was performed in order to understand how other companies have designed their doors. A shorter market analysis is presented in section 4.1.4, the full market analysis can be seen in appendix 1. The competitors that have been investigated are developing machines for agriculture and/or construction equipment and can be seen below:

<table>
<thead>
<tr>
<th>Agriculture</th>
<th>Construction Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fendt</td>
<td>CAT</td>
</tr>
<tr>
<td>Valtra</td>
<td>JCB</td>
</tr>
<tr>
<td>Claas</td>
<td>Gehl</td>
</tr>
<tr>
<td>Bosal-Sekura</td>
<td>Deere</td>
</tr>
<tr>
<td>Huddig</td>
<td>Liugong</td>
</tr>
<tr>
<td>Lännén</td>
<td></td>
</tr>
</tbody>
</table>

INTERNET SEARCH
The companies specified above are a selection of the larger competitors based on internal Volvo CE documents, an Internet search of web pages for retailers and a search of the forum Maskinisten. Since these companies have a big range of products, a selection of the products had to be made, see page 17. This selection is based on products that are operating in a similar environment as the WLOs from Volvo CE and that cover a product design range as large as possible. For the full analysis of the competitors’ products, see appendix 1. The findings show that the majority of the competitors’ machines have a door that is very similar to each other and that today it is common that a door is designed in glass in a large extent.
QUESTIONNAIRE
It was desirable to contact professionals who know what the machine users often feel and think about the products, in this case the doors. Therefore, a questionnaire was sent out to seven retailers of different agricultural machines and construction equipment. Unfortunately, it was hard to receive responses from the retailers’, only two retailers responded. The respondents answered on behalf of JCB, Fendt, Valtra and Claas. Their answers can be seen in appendix 2. Based on the answers from the two respondents their customers have never expressed any opinion about the door. This makes it believed that the door (not depending on brand or door design) is experienced as unproblematic and safe.

FORUM SEARCH
The search at the forum Maskinisten was reviewed in order to collect opinions about doors that the end users may have. Maskinisten is a forum where people with high interests in machines, both agricultural and construction equipment, gathers and discusses thoughts and problems. The whole discussion forum was reviewed without finding any opinion about the doors in the sense of that the user is expressing any difficulty or wants. A conclusion from this is that the door, regardless of company, appears to work well and consumers do not seem to have a problem with either the doors function or design.

FIELD STUDIES
The field studies that have been performed are explained below.

- Volvo CE Hallsberg (Sweden)

A visit to Volvo CE in Hallsberg was made during the project start-up. At the visit, a Volvo CE employee within welding and engineering showed the production of WLO doors. A step of the production is seen in figure 8. There was a particular focus on how the frame of the current door is welded and how the door is assembled. It became clear that it is the welding that takes most time in the production. The welders discussed the difficulty in some cases to achieve the tolerances that are set, and there are many moments were it is difficult for the welder to get close to the objects that are being welded and to make a good weld joint. It was expressed that it is desirable to avoid welding as far as possible to ease the production.

- Lantmännens Eskilstuna

Lantmännens is a retailer of agricultural machines from Fendt, Valtra and Claas (Lantmännens Maskin, 2014a). The doors on the machines were examined in design, type of glass and what components that were used and how they were positioned and designed. Unfortunately, there was no possibility to open and examine all of the doors since the visit was spontaneous. The doors were made of tempered glass that was clear without any components taking up space or reducing the visibility. The overall design of the doors were similar each other. The overall impression was that the doors are modern and not experienced as being unsafe even though there are no frames because of a smaller sealant that covers the edges.
Volvo Customer Center Eskilstuna

A possibility to ride along in a Volvo articulated hauler, see figure 9, was given. It was a simple and unplanned test since the opportunity to ride along came suddenly. However, attention was on the size of the cabin, how the user gets in and out of the cabin and of the general appearance of the door. The observations were made by the author of this thesis. One observation was that of a person exiting out of the cabin. This person chose not to follow the instructions of stepping out with the face fronting the machine and instead walked out with the face out from the machine and jumped from the last step. This is not considered to be a good way of exiting the cabin because of the risk of injury. When riding along in the hauler it became clear that the space inside the cabin is limited. There is no room for a handrail that goes into the cabin, however, along the glass is no problem. Therefore, size and number of parts have been tried to be kept at a minimum in order to save as much space as possible.

4.1.2 Ergonomic test

A good working environment includes that it is simple to reach and use handles and handrails. Therefore, a simple test was made to be able to understand how the drivers of a WLO preferably would want to open and close the door, both from the inside and outside of the cabin and whether the handles and handrails are placed in a way that is ergonomically or not. The author of this thesis performed the test of the current door for a WLO. The test was made by sitting in the seat and testing how easy and comfortable it was to reach and use the handle to open the door from the inside, use the handrail to close the door from the inside and how easy it was to get inside the cabin by using the handrails and outer handle.

LESSON 1

By stepping up on the steps and getting into the cabin the outer grip was tested. One lesson was that the first thing one does is to open the door and wait for it to be fully opened by the gas spring and then use the inner vertical handrail on the door as a grip in order to get into the cabin. Therefore, it is important that this handrail is designed in a way that allows the user to reach it from the outside when the user is on their way up into the cabin. This part of the vertical handrail is horizontal and was perceived as a good direction and simpler than a vertical direction would have been. The handrails can be seen in figure 10.
LESSON 2
One reaches to grab the vertical handrail when sitting in the driver seat and closing the door, see figure 11. Therefore, the vertical handrail needs to be designed and positioned in a way that makes it easy for the user to reach and grab it. As it is now, the handrail is positioned vertically in the part that is made for the user to use for closing the door. This was perceived as more ergonomic and more comfortable for the hand compared to if the whole handrail would have been horizontal.

LESSON 3
Both the inner and the outer handle were perceived as having a good design and position. It was easy to understand how to open the door, both from inside and outside. To have a continuous grip without parts that the hand can hit into the two handrails should either be attached against each other (this would however not be a continuous grip) or be separated. The horizontal handrail should not end at the backside of the vertical handrail since the user risk hitting the hand on the horizontal handrail. However, since the current handrails are designed with safety and ergonomics in mind the design will not be changed.

CONCLUSION
The current handles and handrails in the door are both well designed and well placed. It is easy to reach and use the handles when one is sitting inside the cabin and it is easy to reach the outer handle when entering the cabin. The placement of these details means that the user does not need to raise its arm over shoulder level or bend the body in a stressful position which is in line with Hägg, Ericson and Odenrick (2008, p.176). These components are therefore considered as fully functional for this project and do not need to be altered provided that the design and position are compatible with the concepts that later are to be developed.
4.1.3 DESCRIPTION OF CURRENT DOOR SOLUTIONS
The doors that have special interest in this project are the doors that are used for i.e. the WLO L250G (standard door), the door for compact WLOs i.e. L25F and the door for the WLO L105. These doors are described in the following section. The products from the major competitors have also been in interest where a selection is provided in section 4.1.4, for more details see appendix 1.

STANDARD DOOR
The standard door consists of a welded frame that surrounds the glass. A gas spring is attached to the cabin frame to offer a safe opening and closing by slowing down the door’s movement. The door opens by an inner and an outer handle. These handles are connected to the lock mechanism that is located on the inside of the door. On the inside of the glass are two handrails, a horizontal where the inner handle is attached and a vertical. The vertical handrail has a design that allows the user to get a continuous grip when entering and exiting the cabin. The handrails are welded onto the door frame. The upper right frame corner (seen from front) is slightly bended to be able to be the first corner to abut against the cabin frame and therefore provide a good seal. The standard door can be seen in figures 12 and 13.
COMPONENT DESCRIPTION

Following is a short description of the major components that the standard door consists of.

Frame
Surrounding the glass is a welded frame consisting of steel profiles that the glass is glued onto. The profile can be seen in figure 14. A pretension is welded into the right upper corner so that the corner is the one first to meet the cabin frame. This is preferred in order to get a good seal between the door and the cabin.

Sealing
The current sealant of the door is made of EPDM. The sealant was chosen based on the profile for the frame and is mounted by a hammer in the opening of the frame profile.

Gas spring
The gas spring is welded onto both the cabin frame and the door frame. The gas spring is seen in figure 15.

Glass
The current glass is a sheet of 6mm tempered glass. This means that if the glass breaks it will shatter in many small pieces without sharp edges, which will not hurt a person. Surrounding the glass is also a screen print that protects adhesives from UV rays.

Hinges
Two hinges are used to hang the door, see figure 16. Half of each hinge is welded onto the door frame and the other half is welded onto the cabin frame. The current hinges are considered to be fully functional and do not need to be changed during this project as long as they are compatible with the concepts that are thought of.

Handles
The outer handle can be seen in figure 17. The inner handle is housed in the horizontal handrail and can also be seen in figure 17. These components are connected to each other by among others lock wires that in turn are connected to the lock (not seen in figure).

Handrails
The standard door consists of two handrails, one horizontal and one vertical as seen in figure 18. The horizontal handrail is used foremost to contain the inner handle. The vertical handrail offers the user a continuous grip when especially exiting the door. This handrail is part of the three point grip.
DOOR L105
The main difference with this door compared to the standard door is that the cover that hides the lock and its components is smaller. This makes the glass appear clearer. The inner and outer handles are the same as in the standard door, as well as the two handrails. The door is seen in figure 19.

DOOR FOR COMPACT WLOS
Volvo CE has also compact WLOs. Doors for these machines are often made in glass in a greater extent. The model L25F is as compact WLO and is seen in figure 20. Its door is made entirely in glass. Every component is directly attached into the glass without any panels for the outer handle to be screwed into. This has acted as a great inspiration.

Glass
The glass is like in the standard door a sheet of 6mm tempered glass.

Handles and handrails
The standard components are used as well for this model, being the same as in the standard door.

Sealing
The sealant on this door is glued around the edges acting as a frame. The sealant does not cover the whole edge of the glass as seen in figure 21.

Hinges
The hinges on the L20/50 WLO have a different design compared to the standard door. These are more rounded and have two holes in them to attach the hinges onto the glass and the vertical handrail, see figure 22.
4.1.4 Competitors’ Products
Following is a selection of the competitors’ machines that have been analyzed in the market analysis. Concepts developed during phase 2 have been evaluated against these machines. For the full market analysis, please see appendix 1 where a description of each product and more pictures can be seen as well.

Agriculture
First seen are machines from Fendt, Claas and Valtra, these are seen in figure 23. They are similar in their door design with doors made of glass in a large extent.

In figure 24 are Lännen Lundberg and Lännen showed. The doors are considered as more old fashioned with a stiffer impression.

Lastly, machines from Huddig and New Holland are seen in figure 25. These doors are very similar to Fendt, Claas and Valtra and give a modern and airy impression.

Conclusion Agricultural Competitors
Agricultural companies are trying new designs and are not afraid of trying new ways of looks and technical solutions. The designs of the doors are becoming more glass inspired and have a more modern and softer look. The type of environment that tractors and similar products are operating in is in a way more kind compared to construction sites and parts of the machines can therefore be built in less robust materials in a greater extent.

The doors are becoming more and more frameless. Instead, there is often a sealing with a metal strip inside of it. However, there are still a lot of different designs with frames but the door is mostly in one sheet (not divided into multiple sections), which gives a more modern and not so bulky impression. The handles for opening the door from the outside are similar in design.
CONSTRUCTION EQUIPMENT

The machines from CAT, JCB, Liu Gong and Gehl as seen in figure 26 have doors that are similar each other. They do not have many visible components, which makes the impression of the door modern and clear.

![Figure 26: From top left: ©JCB, ©Liu Gong. From bottom left: ©CAT, ©Gehl](image)

The doors on the machines from John Deere and Bosal Sekura seen in figure 27 are comparable to the ones mentioned above but are divided into two parts, which makes the door appear not as clear as the others do.

![Figure 27: ©John Deere, ©Bosal Sekura](image)

CONCLUSION CONSTRUCTION EQUIPMENT COMPETITORS

Companies that offer construction equipment seems to want doors with more glass than before and doors that have solely one sheet of glass instead of multiple sections. So far, it is not as common to have doors without frames as it is for companies that offer products within agriculture. Though, as showed above there are some exceptions, which shows that the trend is leaning against offering frameless doors. The design of the outside handle seems to have a communal shape and is often similar to the handle that the WLOs from Volvo CE have today.
4.1.5 Why choose glass at all?

There are different reasons for choosing a design with a large amount of glass. Of course, there is a safety perspective and it is natural to have the feeling of “this is not safe”. However, based on the information gathered from questionnaires and forum search this feeling is not expressed. However, this does not mean that this feeling does not exist. Since glass is a material that is safe when processed correctly, used the right way and with a good design, there is no need to worry. Following are the reasons for why glass is considered as a material that works well for the concepts in this project:

Concrete reasons:

- More glass means an improved visibility
- Easier to assemble when no welding is required
- Can lead to a cost reduction since painting and welding of frame is not required

Arguments that can be discussed:

- Gives a more open and airy impression

Since more glass provides an improved visibility it is likely that the impression is that it feels more open and therefore more airy. This is however a subjective opinion and should not be taken as the truth.

- Gives a more modern impression and is timely considering competitors design

The trend seems to leaning against doors that are made of glass in a large extent, are peeled down and have few components that are visible.

- Compact Volvo CE WLO’s are already implementing glass door solutions

To get a consistent appearance of the Volvo CE WLO product range it is assumed that a consistent door design is preferred. Since compact Volvo CE WLO’s have doors made in glass in a large extent, the standard door is considered to be able to have a similar design.
4.1.6 Costs
The cost for the standard door for a WLO is approximately 2100 SEK. The major expenditure items are the profiles for the frame (calculated 407 SEK), panels (176 SEK), adhesives (145 SEK), cover (129 SEK) and a plate (129 SEK). A big expenditure is also the painting (approx. 300 SEK).

The whole list of costs can be seen in figure 28.

To minimize the cost this project has focused on:
- Fewer articles
- Standardized articles
- Easy assembling that saves production time

Figure 28: Cost for standard door
4.1.7 Requirement Specification
A requirement specification has been made that is based on the information discussed during the different field studies and on CTS Documents. The specification can be fully seen in appendix 3. The following points have been prioritized and are copied from the CTS “Preferred solution of doors”:

The requirement specification is confidential.

(Volvo CE, CTS Preferred solutions of doors)
4.1.8 Functional Analysis

The functions that the door needs to meet were analyzed based on the requirement specification and the current door. A door is a very common product and its functions can be considered being obvious. In this case, there are also functions that involve having the user entering and exiting the cabin in a safe way.

Following is the function analysis:

Main function
(A) Enclose the cab space/area (a limited space)

Sub function
(A.1) Enable entering and exiting
(A.2) Enable isolation from within (i.e. being able to close (open) door from inside cabin)
(A.3) Enable improved visibility
(A.4) Enable support inside cabin
(A.5) Being able to open door from outside

Support function
(A.1-1) Offer a safe handle/grip for ingress and egress
(A.1-2) The door provides an extension of the ingress and egress
(A.2-1) The inner handle needs to have an ergonomic design
(A.2-2) The inner handle needs to have an ergonomic placement
(A.3-1) –
(A.4-1) The inner handrails needs to have an ergonomic design
(A.4-2) The inner handrails needs to have an ergonomic placement
(A.5-1) The outer handle needs to have an ergonomic design
(A.5-2) The outer handle needs to have an ergonomic placement
4.1.9 Evaluation of existing solutions

The competitors’ products that were specified in section 4.1.4 have been evaluated and compared against each other and against the standard door in how well they fulfill the requirements. The evaluation was made with Pugh’s matrix and can be seen in appendix 4. A list of the products that have been compared is seen in figure 29. The requirements are the same as in the requirement specification and are weighed after importance based on the information that has been gathered. The evaluation has been made solely based on product pictures, no tests have been performed. The ones considered to fulfill the requirements the least were Bosal Sekura Compact Mobile Crane AC40 (figure 30) and Lännen Lundberg 42000ls (figure 31). These ones were, for example, considered to not ease manufacturing and assembling. Claas Axos 340-310 (figure 32) and New Holland T5 Electro Command Tractor (figure 33) are the ones that were considered to fulfill the requirements the most. These are considered to be very similar to the reference Volvo CE WLO L20F (figure 34) with the one exception of appearing to protect the glass slightly more. For pictures of the products evaluated, see appendix 1.

<table>
<thead>
<tr>
<th>Solution no.</th>
<th>Company</th>
<th>Model</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Volvo</td>
<td>Wheel Loader L20F</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Bosal Sekura</td>
<td>Wheel Loader ADS</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Lännen Lundberg</td>
<td>Compact Mobile Crane 1070, 1120, 1140</td>
<td>-2</td>
</tr>
<tr>
<td>4</td>
<td>Compact Mobile Crane AC40</td>
<td></td>
<td>-16</td>
</tr>
<tr>
<td>5</td>
<td>Valtra</td>
<td>N163</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Fordth</td>
<td>100 Vario</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Claas</td>
<td>Axos 340-310</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>New Holland</td>
<td>T5 Electro Command Tractor</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>CAT</td>
<td>Compact Wheel Loader 900H2</td>
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<tr>
<td>10</td>
<td>JCB</td>
<td>Wheel Loader 4198</td>
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<td>11</td>
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<td>410k TC Backhoe Loader</td>
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<td>16</td>
<td>Bobcat Loader 765A (Parkers)</td>
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</tr>
<tr>
<td>17</td>
<td>Gehl</td>
<td>340 Articulated Loader</td>
<td>-6</td>
</tr>
</tbody>
</table>

**Figure 29: Evaluated products**

**Figure 30: Compact Mobile Crane AC40 ©BOSAL SEKURA**

**Figure 31: LÄNNEN LUNDBERG 42000LS ©LÄNNEN**

**Figure 32: NEW HOLLAND T5 ELECTRO COMMAND TRACTOR ©NEW HOLLAND**

**Figure 33: Claas Axos 340-310 ©CLAAS**

**Figure 34: Volvo WLO L20F ©VOYLO**

©Josefin Hult 2014
4.2 PHASE 2 – CONCEPT DEVELOPMENT PROCESS

Concepts have been developed for both the door as a whole as well as for different components in several stages in an iterative process. The stages will be explained during this chapter. However, for a better understanding of the process a short summarization is being presented first.

4.2.1 SUMMARIZATION OF THE CONCEPT DEVELOPMENT PROCESS

The aim of this project was, when starting this project, to develop a door made in glass in a greater extent than the current solution and where the handrails could be redesigned in order to function with the glass design. With this in mind, concepts covering the whole door and ideas for the handrails were generated and evaluated (1). At the same time, the ergonomic test was performed where the main insight was that the current design and position of the handrails should be kept. This meant that the ideas that were thought of for the handrails were put aside. Instead, focus shifted in order to find what ways the door could be sealed. Different solutions that exist today were looked into and alternatives that were thought to work for this context were stated and evaluated (2). When evaluating the sealant alternatives and overall door concepts, discussions led to the opinion that the hinges that are used today should be used for the new door as well. Since the door at this point is fully in glass the opinions were that the vertical handrail needs to be connected in both of the hinges. This in turn led to that the handrail needed to be redesigned, something that earlier was thought of as unnecessary and that should be avoided since the handrail is designed for ergonomics and safety reasons. Since the handrail needed to be connected with the hinges, ideas from (1) and sealing suggestions from (2) were combined in order to find new overall concepts including the handrail (3). However, at a new evaluation the redesign of the handrail was thought of as not fulfilling the requirements. At this point, a decision was made to disregard the requirement of a three-point grip and, therefore, not lay more time on designing the handrail. Instead, focus was to complete the concept for the whole door and develop a prototype were the functions could be tested, which is the final phase of this process (phase 3).

4.2.2 GENERATING CONCEPTS STEP (1)

In total, ten different concepts were thought of for the whole door/handrails. Handmade sketches and a short description of those concepts can be seen in appendix 5. There are notes on the sketches, though they are in Swedish. However, during the project focus shifted and a decision was made to use the original handles and handrails, which means that concepts for these parts did not become more elaborated.

4.2.3 CONCEPT EVALUATION 1

While the concepts were generated a decision was made to not continue to focus on further developing the handles and handrails. This meant that no evaluation was made for these concepts. The concepts that concern the door in general were evaluated against the requirement specification in order to assess which concepts that had potential and should be further developed. This was a smaller evaluation that only intended to provide a foundation for plausible solutions. The concepts that were thought as most probable were number 1 and 6. These can be seen in figure 35 and are described below.
**Concept 1 Whole door (step 1)**
The door is made entirely in glass without a frame, unlike the standard door. On the inside of the glass is a sealant attached with glue. There is only one handrail that is shaped in a continuous pipe. This allows the user to use the handrail both for support when entering and exiting and to use it to close the door. This would increase the feeling of a glass door. The handrail is attached against the glass with either glue or screws. To get a door that is perceived as a complete glass door the number of details in the glass should be kept as low as possible. A thought was therefore to hide the outer handle and its lock wire inside the pipe frame. However, since the assembling of these parts involves screws and nuts that manually need to be positioned this part of the concept is not feasible.

**Concept 6 Whole door (step 1)**
This concept involves two handrails (one vertical and one horizontal) that possibly are welded together. The vertical handrail is attached in both of the hinges. The horizontal handrail is similar to the original with the inner handle hidden inside of the handrail. A cover is used to hide the lock wires etc. that the handles and lock are connected to. The concept is seen in figure 35.

![Image](image.png)

**Figure 35: Concept 1 and 6 from step (1)**

These concepts were as described before plausible solutions that have been further developed during the PDP.
4.2.4 Generating concepts step (2)
The next step was to generate concepts for the sealant. Based on the information that was found about ways of attaching a sealant and how it can be designed, concepts that were thought to function were generated. The following input was used when generating ideas.

- The sealant can be attached with tape, screws, adhesives or with tooth like parts that is in the sealant’s design, see figure 5 (page 7).
- Clip list with steel core and cellular rubber for increased stability
- Clamping profile/Glazing list

Nine different sealant concepts were thought of. Out of these nine, three were for sealant attached against the cabin frame and the remaining six are for sealant attached against the glass. All concepts can be seen in appendix 6 with a short description.

4.2.5 Concept evaluation 2
The concepts were evaluated in Pugh’s matrix and can be seen in figure 36. It became clear that the most suitable solutions were the ones were the sealant is attached against the glass, not the cabin frame. Mostly this is because it is believed to be easier to get stuck in, and step on, the sealant attached to the cabin frame, thus causing damage on the sealant as well as irritation for the user. The whole Pugh’s matrix can be seen in appendix 7. The requirements that the concepts were evaluated against are requirements that are based on the information gathered in phase 1 about sealants and how the sealant needs to function. The reference was the current solution of a weather strip that is mounted in the profile of the doorframe. The requirements are partly subjective, which makes the evaluation more subjective than if the requirements would have been hard facts.

![Figure 36: Evaluation of sealant suggestions in Pugh’s matrix](image-url)
CHOICE OF SEALING CONCEPTS
From the evaluation five concepts were considered to go through to the next step and were discussed with Volvo CE employees, see description and figure 37-41 below. There are notes on the sketches, they are in Swedish though.

Concept 2.1
A rubber sealing is glued along the inside of the glass edges. It does not surround the entire edge. This concept is a base concept on which the other concepts are built upon. See figure 37.

Concept 2.3
This concept involves a clamping profile (also called glazing strip), normally in hard plastic, that is U-shaped and surrounds all of the edges of the glass. The profile is attached with toothlike parts that mean that no glue or tape is needed. See figure 38.

Concept 2.4
A continuation on concept 2.3. An aluminum fronted profile with rubber inside that is glued against the glass. The profile covers all edges. See figure 39.

Concept 2.5
A clamping profile with extra sealing against the cabin frame in form of a weather strip. The sealing is attached as concept 2.3 with toothlike parts against the glass (no glue or tape needed). See figure 40.

Concept 2.6
Similar to concept 2.1 but has an L-shape that surrounds the outer edge and the front side. The profile is rounded and taped against the glass. See figure 41.

These concepts were taken to the next step (3), which is described in the next section.
4.2.6 Generating concepts step (3)

After the first two steps, step (1) and (2), concepts for both the whole door and the sealing had been generated. After the evaluation of those concepts, the concepts that were thought as the best were combined. This resulted in five new concepts (based on the whole door, sealant and new design of the vertical handrail) that were thought as better suited. These concepts were presented for the industrial supervisor and a Volvo CE colleague. The concepts are partly alike with sometimes component solutions in each making parts of the concepts similar. Larger sketches of the concepts can be seen in appendix 8.

Concept 1
This concept concerns a door made entirely in glass with a clamping profile or a glued U-shaped profile list that surrounds all glass edges with either a rectangular or a circular form. There are two handrails, one vertical and one horizontal. The horizontal handrail holds the inner handle. The vertical handrail is formed as the original handrail. If the sealant is glued against the glass, a plastic film is needed to protect the glue from UV-rays. This film could be slightly enlarged to give the impression of a frame and by that increase the feeling of that the door is safe to use. The outer and inner handles are the standard components. See figure 42.

Concept 2 and 3
These concepts are the same as concept 1 but the sealant suggestions are thinner. The sealant could either be glued on the inside of the glass, not covering the edge, or a L-shaped taped sealant that would leave a sharp edge in the corners. It can also be a clamping profile that covers all edges and is attached without glue or tape. The glass corners are rounded, not sharp, to give a softer look and at the same time decrease the risk of tension. The difference between concept 2 and 3 are the sealant suggestions for the whole door. See figure 43.

Concept 4
This concept suggests a door that is partially framed. The frame covers the left and upper side of the glass. This is assumed to ease the pretension in the upper right corner (seen from front) and provide a good seal against the cabin frame. The glass is glued against the frame. See figure 44.
Concept 5
This concept involves two different handrails. The first one is the horizontal where the inner handle is housed and the second one is the vertical. The vertical is mostly used for closing the door when the user is inside the cabin and to have as a support and three-point grip. Another component is the hinges that were considered to be needed as attachment points. This meant that the vertical handrail needed to be elongated in order to reach each hinge. This in turn meant that the angle and design of the original handrail was altered. The experience from the ergonomic test was in mind when developing a good grip at the bottom of the door when entering and exiting. To avoid a stiff and square impression a softer shape was seen as more pleasant and the vertical handrail became rounded at the bottom to ease the grip. The angle that the horizontal handrail attaches against the glass has been changed but the main design from the original handrail is kept. See figures 45 and 46.

4.2.7 Concept evaluation 3
The Pugh’s matrix was considered to be used once again, but since the concepts were built on several different components it was seen as an evaluation by the matrix would not give a clear result. Instead, the concepts were discussed and evaluated against the requirements with the industrial supervisor and colleagues at Volvo CE. During the discussions about the vertical handrail, with its new angle and not a continuous grip, the opinion was that the handrail was not considered to fulfill all requirements. Because of this and the shortness of time left in the project the discussion led to a decision of not continue to generate concepts of new handrail designs. The evaluation did not lead to a single concept that was seen as the best one. Instead, the opinions were that the best glass door solution at this point consists of a sealant that covers all edges and that is easy to attach and a (vertical) handrail that supports the glass and gives a pretension.
4.3 PHASE 3 – DEVELOPMENT OF THE DETAILED CONCEPT
When getting to this point, concepts have been generated about all major components. This part of the PDP aims to put all parts of the best suited concepts, based on the evaluation of the combined concepts (3), into one concept. This new concept aims to make all components work with each other. The main priority has been to develop a concept that is easy to assemble and that leads to an impression of a door that is made in glass. During the development of the detailed concept, feedback has been given from an engineer/welder at Volvo CE Hallsberg who examined the CAD-parts and gave his opinions from a manufactures/welders point of view in order to improve the concept. Continual discussions have also been made with Volvo CE colleagues at the cab division. It is their opinions and the results from earlier phases that have helped creating the detailed concept whose process is described below.

4.3.1 DESIGN OF HANDRAILS
The horizontal handrail houses the inner handle and lock wire and it was re-designed in order to be attached against the glass. Otherwise, the focus has been on keeping the original design of this handrail. The development of the vertical handrail had shifted focus from having a three-point grip to find a solution that can facilitate the pretension in the upper right corner to provide a good seal. The suggestion for the vertical handrail has been developed with the help of CAD. With many small changes and the help of Volvo CE colleagues, the vertical handrail has a simple design. In order not to conceal the glass, the vertical handrail got the design of following the vertical line of the glass edge for a coherent impression. The handrail needs to be continued at the bottom end and be elongated to allow a three-point grip but as stated earlier this requirement has been disregarded. The position of the vertical handrail has been chosen with the guidelines from Pilkington (Pilkington, 2014b). The standard involves how far from the glass edges holes can be made for attachment of components. This position of the handrail should also facilitate the RPS points where the hinges can act as two of the points in the triangle.

4.3.2 CHOICE OF SEALANT
Sealant around glass edges
Contact has been taken with Industripartner (external supplier) when looking for a sealant that would fulfill the requirements. Industripartner recommends a clip list since this type of sealant is flexible and easy to assemble. The sealant solution is based on the alternatives that Industripartner suggested from Kuntze AB (Kuntze, 2014). It is protecting the glass around all the edges based on the opinions that came up during discussions with Volvo CE colleagues. The sealant profile has been re-designed several times before getting to a dimension that seems plausible and that is filling the gap between the door and the cabin frame. Unfortunately, even though there has been an extensive search for an existing sealant with a profile that is similar to the one designed no one has been found given the time limit of this project. To find an existing sealant that is similar to the developed profile is therefore seen as a recommendation, see section 7.2.3.

Sealant in glass and under components
To protect the glass from shattering when attaching components it was considered as necessary to have a rubber sheet between each component and the glass (Industripartner, no date). Each sealant has the same base dimensions as the component that it is intended for, but is 2 mm wider than the component to allow easy attachment and good sealing. The suggestion is once again based on the advice from Industripartner. Because of lack of time during the final part of the process, there is no
final suggestion for the sealant that is inserted into the cutouts in the glass (a bushing). However, there needs to be a rubber bushing to protect the glass. The bushing is preferably around 2 mm thick in order to take up the tensions that occur when inserting screws based on discussions with a Volvo CE employee within engineering.

4.3.3 Choice of Handrail Holders
To attach the handrails against the glass two variants of handrail holders have been designed in the CAD environment. Because of information that came late into the project about standard components that could be an alternative these handrail holders should not be considered to be the best proposal. Here the function, not the design should be in focus. Since the standard BS EN ISO 2867:2011 states that it must be a distance of at least 50 mm between handrail and glass there needs to be a holder that attaches the handrail at this distance. The holder made for the vertical handrail needs to have a shape that surrounds the handrail and that is planar to the glass so that the holder connects to both the handrail and the glass. The other holder is made for attaching the end of both of the handrails (pipe ending) against the glass. The components have been designed with DFMA in mind by wanting it to be as easy as possible to attach the screws etc. by not have too small dimensions or tight space.

4.3.4 Choice of Hinges
The aim was to use the original hinges as far as possible. However, to be able to attach the hinges against the glass it was needed to make holes in them. The hinges got the same width as the handrail fastener for the vertical handrail so that the holes had the same position in both of the components. It was considered important that the hinges could be attached at the same points as the original hinges in order to be aligned with the interface of the cabin frame.

4.3.5 Choice of Handles
The inner and outer handles are both the original parts and have not been altered since there has not been any information that shows that they needed to be re-designed.

4.3.6 Choice of Gas Spring and its Holder
The gas spring is the original part. On the standard door are the attachment points for the spring welded against both the doorframe and the cabin frame. The position of the attachment point on the cabin frame is preferred to stay the same in order to not have to make changes on the cabin frame. Since it is not possible to weld the attachment point onto the glass the vertical handrail has been used as an attachment point. However, a holder is suggested because the handrail cannot be at the same distance from the upper glass edge as the attachment point normally is on the standard door. The purpose of the holder is to get the attachment point to the same height as the original point. The design of this component should not be seen as a finished solution.

4.3.7 Choice of Lock Mechanism Parts
The main lock mechanisms and lock wires are the original parts. The one part that has been changed is the holder that attaches the lock against the glass and the horizontal handrail. The lock holder is based on the original design but with smaller changes in order to have the horizontal handrail and its lock wire meet the cutout in the holder. Two parts used for fixing the main lock in the original lock mechanism have been removed since they do not hold any function in this concept.

4.3.8 Choice of Glass
Based on the glass used in the standard door the same base dimension and glass type
has been considered the most suitable option, i.e. a 6mm tempered sheet of glass. This decision is also based on discussions with Volvo CE engineers that says that tempered glass means an easier manufacture and lower costs compared to a laminated glass but with sufficient mechanical properties, which fulfills the safety requirements (SS-EN 572). The glass has cutouts to suit against the screws that attaches the components. The cutouts have in general been made 3 mm larger than the diameter of the screws in order to have space for screw and bushing.

4.3.9 CHOICE OF FASTENERS
Each component that needs to be attached against the glass or to another component were considered to be easiest attached with screws, washers and nuts. The number of screws that are considered as necessary is not confirmed. Since it is hard to tell how a glass door will act when used in the field the opinion has been that it is safer to have two screws per part of the component that is attached against another component or glass. If a prototype test gives a result that shows that the components and the glass are stable, a lower number of fasteners could be tested to see if the door still fulfills all requirements, see recommendations section 7.2.6. It is also a recommendation to use standardized dimensions, see section 7.2.7. This recommendation is built on information that came late into the project regarding dimensions that usually is used within Volvo CE.

4.3.10 COVER
A cover is recommended in order to hide and minimize the risk of a person getting stuck in the lock and the lock wires from the outer handle. When developing the cover the function rather than the design has been in focus and because of the time limit a final suggestion of the cover has not been made. The cover has been developed (see section 5.1.10) with the shape of the side edge of the glass (figure 47) and the lock holder in mind to achieve a coherent appearance. In order to avoid having cutouts in the glass a solution is suggested of using the plate that the outer handle is connected to, which the cover can be attached against. By this, it would be possible to attach the cover against the glass with two screws where only one is attached through the glass.

4.3.11 THE DETAILED CONCEPT IN SUMMARIZATION
The detailed concept that also is the result of this PDP can be seen in figure 48 and is described more in detail in the result chapter, see page 34.

The door concept consists of:

- A tempered sheet of glass
- Two different handrails
- Two different kinds of handrail holders
- A sealant that covers the glass edges
- Sealant that is placed between components and glass
- An inner and outer handle
- A lock mechanism and lock holder
- Two hinges
- A gas spring and its holder
- Fasteners
- Cover (not seen in figure)
4.3.12 Concept Evaluation 4
To evaluate the detailed concept a prototype has been developed. However, the prototype has not been finalized when submitting this report. It is therefore a recommendation (see section 7.2.6) to test the functions of the door in order to evaluate the concept and find opportunities for improvement.

Prototype
Drawings on all components, a bend table for the handrails and DFx-files have been made to be able to manufacture the prototype. The drawings were made only for the purpose of being functional for making a prototype. The conceptual drawings can be seen in appendix 9 and the bend table for the handrails can be seen in appendix 10.
5. RESULTS

The components that are used in the detailed door concept are described during the following section. For a BOM-list for all components being used, please see appendix 11. The result should be looked at as a suggestion that can be further developed with future test result from the prototype as well as design in mind. The suggestion should therefore not be looked at as a final product that can be implemented into production immediately.

5.1 THE GLASS DOOR

For a comparison, the standard door (without cabin frame) is seen to the right (figure 49). For more and larger CAD-pictures, please see appendix 12.

5.1.1 GLASS

The glass is a sheet of 6mm planar tempered glass. This is following the standard of thickness and glass type in CTS Preferred solutions of doors. The corners are slightly rounded to reduce the risk of tensions. The cutouts that have been made are following the guidelines from Pilkington (Pilkington, 2014b). The glass has also a hole that is made for the cover but should not be seen as a final dimension or position. The dimensions of the cutouts are in average 3 mm larger in order to fit the rubber bushings and the screws.

5.1.2 HANDLES

The inner and outer handles are the same components as used in the standard door. The handles are seen in figure 50. The outer handle is attached against the glass with the original screw (M28).
5.1.3 Hinges
There are two hinges that hang the door. These are based on the original hinges that are used in the standard door with the exception that they have been elongated and gotten four holes. These holes are used to attach the hinges against the glass. Seen in figure 51 is the hinge that is attached against the glass. The hinges have the same position as the original hinges in order to align with the interface of the cabin frame.

5.1.4 Handrails
There are two handrails, one referred to as the horizontal and one as the vertical. The handrails are seen in figure 52. The handrails have been re-designed but the design is not finalized since the requirement of a three-point grip was removed. This applies especially to the vertical handrail since that handrail can be designed in order to facilitate entering and exiting. The handrails have the diameter 25 mm and a thickness of 2 mm following the requirement Volvo CE has. The horizontal handrail has a cutout to accommodate the inner handle and lock wire. This cutout is the same as in the original horizontal handrail. The vertical handrail has been elongated and bent at the left (seen from inside the cabin). The handrail has been elongated in this direction since the upper left corner (seen from inside of cabin) needs to be the first corner to seal against the cabin frame. By elongate the handrail a better support of the glass and a higher pretension can be obtained and facilitate the seal.

5.1.5 Handrail holders
There are two different kinds of handrail holders, one to attach the end of the handrail against the glass (figure 53) and one to support the glass by attaching the vertical handrail against the glass and the hinges (figure 54). Based on the standard BS EN ISO 2867:2011 the holders are designed to keep the handrails at a distance of at minimum 50 mm from the glass.

The holders are attached against the glass with M8x35 and corresponding washers and nuts. M5x40, washers and nuts are needed to attach the handrail against the holder. The handrails have corresponding holes to match the holes in the holders.
5.1.6 **Lock mechanism and its holder**
The lock mechanism and the lock holder are seen in figure 55. The holder is attached against the glass with an M8x35 that secures the locker to the glass. The holder has the same position as the original part to ensure that the locker matches the point on the cabin frame that the locker attaches against. This is to be able to lock the door. The horizontal handrail and its lock wire are concentric to the cutout in the holder to enable the wire to attach against the lock.

5.1.7 **Gas spring and its holder**
The original gas spring is used. The spring is attached onto its holder with an M8x50 that in turn is attached on the vertical handrail with an M5x40. The holder is used in order to get the right distance from the attachment point to the cabin frame. The design on the holder should not be seen as the final suggestion. The holder, ball joint on which the spring is attach to (original part) and the gas spring can be seen in figure 56.

5.1.8 **Sealant**
The sealant has been chosen based on recommendations from Industripartner and is made of EPDM. Its dimensions are based on filling out the space between door and cabin frame but should only be seen as suggested dimensions. A functional test should be made in order to ensure that the sealant fulfills the requirements for i.e. air and water tightness. The profile of the sealant can be seen in figure 57.

5.1.9 **Rubber protection for components**
There are two types of rubber protections: sealant under components and rubber bushings that are inserted into the cutouts in the glass. The sealant is a 2 mm thick rubber sheet based on existing products from Industripartner (Industripartner, no date). Each sealant has the dimensions as the component that it is protecting the glass from but is 2 mm wider to ensure that the glass is fully protected from being damaged. The sealant placed under the hinges in seen in figure 58. There are also two different dimensions of rubber bushings. The dimensions depend on the diameter of the cutout in the glass. The bushing is made of rubber to protect the glass from shattering and take up the tension that occur when inserting the screws.
5.1.10 COVER
The cover is made to protect a person from getting stuck in and cover the parts for the outer handle, the lock mechanism and its lock wires. The cover is seen in figure 59. This component is not finalized, see recommendations in chapter 7.2.4.

5.1.11 FASTENERS
In order to minimize the number of different components, the fasteners that have been used are primarily M8x35 and M5x40 with corresponding dimension for washer and nuts. Late into the project was information given that M6 should be used instead of M5. A recommendation is therefore made to change from M5 to M6 if further development will be done, see recommendations 7.2.7.

5.1.12 RPS
To be able to use RPS, different points needs to exist. It is believed that the original points can be used, as seen in figure 60.

5.2 PROTOTYPE
A prototype was developed late into the project and was at submission of this report not finished. For the purpose of solely test the function of the door the chosen glass was one-curved.

5.3 ASSUMED STRENGTH
The door concept should have sufficient strength based on a comparison of existing solutions. Standard components have been chosen as far as possible and standards and guidelines have been followed making it believed to assure the strength.

5.4 ESTIMATED COST
By removing the frame a large expenditure is eliminated since there is no welding or painting of the frame required. The door is therefore assumed to have a lower cost than the standard door but since all components have not been finalized the costs have not been investigated further.
6. ANALYSIS
This chapter aims to analyze how the method with the three phases has helped the process and give a result that has answered the RQs. The process to the answers and the answers themselves will be analyzed. Ending this chapter is an analysis of which requirements the detailed concept fulfills.

To support the memory, the RQs have been the following:
RQ1. How can the WLO door be designed in order to ensure that strength, function and safety requirements are met?
RQ2. What are the arguments for designing a WLO door in glass without a frame?
RQ3: Which functions does the WLO door need to fulfill?

6.1 PHASE 1 - INFORMATION GATHERING
During the first phase RQ2 and 3 were meant to be answered. They have been answered by methods like field studies, forum search, questionnaire and an ergonomic test. These methods have, except the questionnaire, been considered helpful and provided relevant information for the assignment.

6.1.1 FIELD STUDIES
The field studies helped gather information that proved valuable. The visit to Volvo CE Hallsberg gave the first deeper contact with the standard door. The visit was made during the first week of the project, which means that no real understanding of the problem had been obtained at that point. Even though much information was provided during the visit it is possible that it could have been even more valuable if there would have been time to understand the problem better and, therefore, have the knowledge of knowing what to ask. Visits to Lantmännen and Volvo Customer Center gave a greater understanding of how the products, both Volvo CE products’ and competitors’ look like in real life and which possibilities that exists. Not least, a base was obtained that was used when evaluating concepts.

6.1.2 FORUM SEARCH
The search at the forum Maskinisten was made with the intention to find honest opinions from end-users. The search was extensive and time consuming and even though no clear opinions were expressed the silence was interpreted as there are no problems in general with doors for construction equipment or agricultural machines.

6.1.3 ERGONOMIC TEST
Information was gathered about ergonomics and how position of handles and handrails should be. The components in the standard door were ergonomically tested, which provided valuable knowledge. The test results were in line with the theory about how handles and handrails should be positioned. This was a good starting point of information for the concepts that later were to be developed in phase 2.

6.1.4 QUESTIONNAIRE
The one thing that did not work as well as hoped was the number of questionnaire responses from retailers of agricultural and/or construction equipment, only two answers were received. In agreement with Bell (2006, pp.151) the answers were still valuable but in order to collect a larger amount of data this is not seen as sufficient.
6.1.5 RQ3: WHICH FUNCTIONS DOES THE WLO DOOR NEED TO FULFILL?

Functions for a door can easily be thought of and the information gathering with ergonomic test, field studies and forum search did not show any exceptional new functions. However, it was still considered important to reflect over the functions that the door needs to fulfill in order to not forget the obvious (therefore making it into a RQ).

Functions that the standard door is fulfilling today are among others:

- Providing three-point grip for safe entering and exiting
- Opening and closing of door, both from inside and outside

The function that a glass door would contribute with is:

- Improved visibility

The functions that the glass door needs to meet are:

Main function
(A) Enclose the cab space/area (a limited space)

Sub function
(A.1) Enable entering and exiting
(A.2) Enable isolation from within (i.e. being able to close (open) door from inside cabin)
(A.3) Enable improved visibility
(A.4) Enable support inside cabin
(A.5) Being able to open door from outside

Support function
(A.1-1) Offer a safe handle/grip for ingress and egress
(A.1-2) The door provides an extension of the ingress and egress
(A.2-1) The inner handle needs to have an ergonomic design
(A.2-2) The inner handle needs to have an ergonomic placement
(A.3-1) –
(A.4-1) The inner handrails needs to have an ergonomic design
(A.4-2) The inner handrails needs to have an ergonomic placement
(A.5-1) The outer handle needs to have an ergonomic design
(A.5-2) The outer handle needs to have an ergonomic placement

6.1.6 RQ2: WHAT ARE THE ARGUMENTS FOR DESIGNING A WLO DOOR IN GLASS WITHOUT A FRAME?

This question can be considered to be a crossroad, therefore making it into a RQ. If there would not have been any arguments for why it is seen as positive to have doors entirely in glass the aim of this project would not have any reasons to be fulfilled. The benchmarking with, for example, the forum search and the field studies showed that there are many products similar to the WLOs from Volvo CE that have frameless doors. This makes it possible to draw the conclusion that it is seen as positive with doors made in glass in a great extent. The information that was found during the benchmarking is the following.

Designing a door in glass in a larger extent gives in general:

- An improved visibility
• The impression of being more open and airy

In this circumstance, a WLO door made in glass in a larger extent means:

• Easier assembling and lower cost because no painting or welding of a frame is required
• A more coherent design of WLO doors since some compact Volvo CE WLOs already have similar glass door solutions. This may also increase the recognition of that it is a Volvo CE WLO that is seen.
• A more modern and timely impression considering competitors’ products

6.2 PHASE 2 - CONCEPT DEVELOPMENT PROCESS

This phase has taken most time and focus, which has been in line with the IDEO philosophy. Even though there is no RQ directly linked to this phase, the main RQ (RQ1) could not have been answered without this phase. The process has been highly iterative with having to go back and re-generating new concepts multiple times. This is mostly because new wants were expressed, in particular about the vertical handrail and much time was, therefore, laid on generating concepts for this handrail. In the end, the requirement regarding a three-point grip was regarded and much work that had been done could not be used. However, this was necessary in order to finish the project on time.

6.3 PHASE 3 - DEVELOPMENT OF DETAILED CONCEPT

During phase 3, the detailed concept was developed based on the information that the earlier phases had provided and helped answer RQ1 that was the main question.

Highest focus during this phase was to make all components work with each other and come to a conclusion on how the detailed concept should be designed. Much time was also laid on producing drawings, bend tables and other documents needed to develop the prototype. Unfortunately, the prototype was not finished at submission of this report making it impossible to test the detailed concept in reality during the project. It is believed that when testing the prototype it will be shown that further development is required. The sealant will most certainly need to be further looked into in order to make sure that the space between the cabin frame and the door is sealed properly. However, the functions of the door are believed to function in a correct manner.

6.3.1 RQ 1: HOW CAN THE WLO DOOR BE DESIGNED IN ORDER TO ENSURE THAT STRENGTH, FUNCTION AND SAFETY REQUIREMENTS ARE MET?

Following are the answers to the aspects in RQ1 discussed.

STRENGTH
The result is based on competitors’ products, Volvo CE-products and the standards that are stated in the Volvo document CAST Preferred solutions for doors. It is, therefore, assumed that the door holds enough strength for the intended functions. A prototype is at submission of this report being developed and is intended to be used to test that the detailed concept is fulfilling all requirements (see recommendations 7.2.6).

FUNCTION
The functions are met by:

(A) **Main function: Enclose the cab space/area (a limited space):**
The door can be closed from both inside and outside and has a sealant that fills the area between door and cabin frame.
**Sub functions**

*(A.1) Enable entering and exiting*

Having handrails that support the user when entering and exiting the cabin. However, the vertical handrail is not finalized, see recommendations chapter 7.2.2.

*(A.2) Enable isolation from within (i.e. being able to close (open) door from inside cabin)*

Having inner handrails that the user can use to pull the door against the cabin frame and by that close the door.

*(A.3) Enable improved visibility*

The glass does not have a frame or a larger cover like the standard door, which makes the glass clearer.

*(A.4) Enable support inside cabin*

There are two handrails that the user can grab hold of if support is needed.

*(A.5) Being able to open door from outside*

An outer handle supports this function.

**Support functions**

*(A.1-1) Offer a safe handle/grip for ingress and egress*

*(A.1-2) The door provides an extension of the ingress and egress*

Like (A.1) the intention is to have a vertical handrail that offers a three-point grip but the design is not finalized.

*(A.2-1) The inner handle needs to have an ergonomic design*

*(A.2-2) The inner handle needs to have an ergonomic placement*

*(A.4-1) The inner handrails needs to have an ergonomic design*

*(A.4-2) The inner handrails needs to have an ergonomic placement*

*(A.5-1) The outer handle needs to have an ergonomic design*

*(A.5-2) The outer handle needs to have an ergonomic placement*

The handrails have the same placement as the original handrails that are ergonomically placed in mind. The design of the horizontal handrail has only small differences compared to the original part, which makes it believed to be ergonomic. The design of the vertical handrail is not finalized. The design and placement of the outer and inner handles are the same as the original making the functions regarding these components fulfilled.

**SAFETY**

The glass is tempered, which lowers the risk of a person getting hurt if the glass breaks. The handrails that are presented in the concept can be used for ease entering and exiting and closing the door, but they are not finalized and should not be considered to provide a three-point grip in line with standard ISO 2867:2011(E). A gas spring is used to slow down the doors movement minimizing the risk for the user squeezing its hand or similar. The handrails have been positioned at a minimum distance of 50 mm from the glass according to standard BS EN ISO 2867:2011 to lower the risk of a person having his or her hand stuck in-between the glass and handrail.

**COST**

Since it was expressed that it was desirable that the door is cost effective an analysis of the result regarding cost is provided.
It is possible that the cost for the glass is higher than that of the glass for the standard door since it has more cutouts. However, without a frame that needs to be welded and painted it is assumed that the total cost is lower than the standard door. Information was provided late into the project about standard screw dimensions and already used holders that could have been used instead. Using these components will most certainly result in an even lower cost. A recommendation has been made since the cost is assumed and there are possibilities to lower the cost with standard components. The recommendation can be seen in section 7.2.7.

6.4 VALIDATION AGAINST REQUIREMENT SPECIFICATION

In order to assure the quality, the result is validated against the requirement specification. The result does not fulfill all the requirements that were set up at the beginning of the project. This is mainly because requirements have changed during the process and that some requirements can only be validated through test of the prototype, which has not been made at submission of this report. To see recommendations about the requirements that were not fulfilled, see section 7.2.

Following are the requirements stated and a comment for each. The numbers are not in numerical order since the requirements have partly been copied from a specification that includes requirements that are not applicable for this case.

Note: Black marked information is confidential.

1.1 Water tightness
Water tightness shall be done according to technical regulation HUTB6001 Cab water test specification Version HUTB6001-04 describes test of complete cabs on machine types WLO, ART and EXC.

Not validated against because the solution needs to be tested.

1.2. Air tightness
Ability to keep inside Cab pressure of 50Pa, total Cab test (Acc. to ISO 10263:1994 Earth-moving machinery - Operator enclosure environment.

Not validated against because the solution needs to be tested.

1.3 Reference Point System (RPS)

This requirement has been kept in mind when developing the door but the RPS coordinates have not been chosen. The standard RPS coordinates are assumed to be functional but this has not been confirmed. The requirement is not fully validated.

1.4 Cost
The cost for the final product cannot exceed the cost for the standard door
Final cost has not been collected and the requirement is therefore not validated.

1.5 Ease of manufacture
Is considered as validated, components have been designed to facilitate manufacturing.
1.6 Ease of assembly

Is considered as validated, components have been designed to facilitate assembly.

2.1 Sealing

A new alternative of sealing has been chosen since the common sealing solutions are used for welded frames and to fit the frame profiles. The requirement is therefore not validated but the solution is considered to be satisfactory provided that the sealant fulfills requirement 1.1 and 1.2.

2.2 Choice of material must be appropriate to the working environment of the door

The material of the sealant is EPDM, which is a standard material. The requirement is validated.

3.0 Functionality requirements

3.1 Position of handle

The handle should be positioned in such a way that visibility through the door is not impaired

The handles have the same position as in the standard door. The requirement is validated.

3.2 Position of handrail

3.2.1 The handrail should be positioned in such a way that visibility through the door is not impaired

The horizontal handrail has the same position as in the standard door. The vertical handrail is thought to have the same position as in the standard door. The requirement is not fully validated but is considered as satisfactory.

3.2.2 This requirement has been disregarded during the project.

3.3 Three point grip

This requirement has been disregarded during the project.

4.0 Ergonomic requirement

4.1 Handles

4.1.1 Handles should be easily accessed and operated from chair

4.1.2 Handles should be easily accessed and used from the steps outside cabin

These requirements are validated since the original handles and placements are used.
4.2 Handrails

4.2.1 Handrails for entering/exiting, and handrails exposed to on-road traffic, should have a reflective tape or paint, at least on a small part of its length.

4.2.2 Handrails should preferably be in a contrasting color against the background. When it not is realistic to meet the standard fully, it is important to design an entrance that is as ergonomic and safe as possible under the condition. If we do that and are among the best in market, we are probably safe from a legal point of view.

These requirements have been disregarded during the project.

5.3 The door must be applicable to the existing wheel loader cabs

This requirement is validated for cabs using the standard door that is adapted for the interface of the cabin frame.

5.4.4 Diameter

The diameter used is 25 mm, making the requirement validated.

5.4.5 Space around handrails

The space is at a minimum of 50 mm and the requirement is therefore validated.

6.4.1 Summarization of the fulfilled requirements

The status of the requirements is seen in figure 61.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Fullfilled</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confidential information</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations that this PDP has resulted in are outlined in this chapter.

7.1 CONCLUSIONS

Below are conclusions about the result, method and process discussed.

7.1.1. RESULT

The result of the project is a frameless glass door. The door meets to a large extent the requirements that were set and with further development will be able to meet the remaining requirements. Therefore, the main conclusion that is drawn is that it is fully possible to develop a door made in glass in a larger extent than the current door. When developing a glass door one of the concerns is to have a door that is perceived as safe and in the meantime is perceived as a glass door. Since the assignment only covered to develop a door that fulfills strength, function and safety requirements, how to design the door so that it is perceived as safe is left for the next phase. New parts have been developed to attach all components against both each other and against the glass. With future prototype results and further development, it is seen as the door has potential to be fully functioning. A major focus at Volvo CE is to develop cost effective products. The door concept is built on standardized articles and has no frame that is a large expenditure, and if the recommendations are followed (section 7.2) it is believed that the door will lead to a cost reduction.

7.1.2. METHOD

The methods being used have been usable. However, when looking in retrospect a questionnaire may not have been an effective method for this case. Instead, direct contact should have been made in a larger extent to gather user opinions. The same conclusion applies to database searches that unfortunately did not provide relevant information. The different field studies have been seen as efficient in providing hands-on-knowledge when production of the current door and machines were seen in reality.

7.1.3. PROCESS

During the project, there have been moments when it became clear that developing a door is more complex than one might believe at first. The process has been highly iterative, which has led to having to go back in the process that in turn has taken much time and at times halted the project’s progress. Having an iterative process have also meant that the result has been able to be quality assured since continuous discussions have been held and PU-tools have been used to reach the result.

Another conclusion from the project is that developing a prototype takes time. Unfortunately, the prototype was not finalized in time. This made it impossible to perform tests that were meant to test the functions and design of the door so that a more refined concept could have been presented.

When starting this project, the author had no experience or knowledge of construction equipment and had not thought about doors more than in everyday life. It has therefore been a very rewarding time since the project has covered many of a PDPs phases and much has been learnt when researching and developing all of the components.
7.2 RECOMMENDATIONS
The result that is presented shows a suggestion on how the door can be designed. Since it is not a final proposal, more work is needed if there is interest in continuing the development of the glass door. Following are the recommendations that in first hand need to be looked into if the process is to be continued.

7.2.1 GLASS
It is possible that a glass curved in multiple directions could give a better seal and contribute to a door that is more stable. If there is a future need for a safer type of glass, glass made of polycarbonate can be an alternative. Sjöholm (Hiab, 2014) states that “Bended glass of polycarbonate does not cause glare, gives better room and visibility and is impact resistant” (author’s translation).

7.2.2 VERTICAL HANDRAIL
The vertical handrail needs to be further developed in order to meet the requirement of a three-point grip.

7.2.3 SEALANT
The sealant suggested needs to be tested in order to investigate if it fulfills the requirements, especially regarding the requirements 1.1 Water tightness and 1.2 Air tightness.

7.2.4 COVER
A cover needs to be developed to protect both the lock parts from damage and to protect people using the door from getting stuck in the lock wires. To have a clearer glass it is also a recommendation to investigate if the outer handle can be re-positioned. If the outer handle could be placed higher up, a smaller cover would be needed, which would result in a clearer glass.

7.2.5 GAS SPRING HOLDER
The gas spring holder has potential of being further developed to obtain a more pleasant design.

7.2.6 PROTOTYPE TEST
The prototype should be tested to ensure that all functions and requirements are fulfilled. Based on the results further development is likely to have to be made.

7.2.7 COST REDUCTION
To lower costs, standard dimensions on all fasteners should be used i.e. the M5 screw should be changed to M6. The same applies to the holders that attach the handrails against the glass. The holders that are being used on backhoe loaders are an alternative that could be looked into. It could also be investigated if the holders could be glued against the glass instead of using screws. This would lower the cost of the glass since the cutouts would be reduced.

7.2.8 GLASS DOOR THAT IS PERCEIVED AS SAFE
To produce a door that users feel is safe, product design including semiotics should be investigated.
8. REFERENCES

8.1 LITERATURE SOURCES


8.2 INTERNET SOURCES


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Korff, Andreas. Engineer/Welder Volvo CE Hallsberg
9. APPENDICES

1. Market Analysis
2. Questionnaire Responses
4. Evaluation of Existing Products
5. Concept Sketches step 1
6. Concept Sketches step 2
7. Evaluation of Sealant
8. Sketches of Combined Concepts
10. Bend Table for Handrails, confidential.
12. CAD Photos of Door Concept
## Contents

**Competitors** ........................................................................................................................................... 2

- Agricultural companies and their products ................................................................. 3
  - Fendt ............................................................................................................................................... 3
  - Claas ........................................................................................................................................... 4
  - Valtra ........................................................................................................................................ 4
  - Lännen ....................................................................................................................................... 5
  - Huddig ....................................................................................................................................... 5
  - New Holland ............................................................................................................................. 6

- Future trends ................................................................................................................................. 6

- Conclusion agriculture ............................................................................................................... 6

**Construction equipment companies and their products** ..................................................... 7

- JCB ............................................................................................................................................... 7
- CAT .............................................................................................................................................. 7
- John Deere .................................................................................................................................. 8
- LiuGong ....................................................................................................................................... 8
- Bosal-Sekura .............................................................................................................................. 9
- Gehl ............................................................................................................................................. 10

- Conclusion construction equipment ...................................................................................... 10

**References** .................................................................................................................................. 11
**Competitors**

The are two main fields of competitors in the design of glass doors; companies within agriculture and within construction machines. The ones listed below are a larger selection of these competitors.

**Agriculture:**

- Fendt
- Claas
- Valtra
- Lännen
- Huddig
- New Holland

**Construction equipment:**

- JCB
- CAT
- John Deere
- LiuGong
- Bosal-Sekura
- Gehl
Agricultural companies and their products

Fendt
The door seen in figure 1 consists of a sheet of glass that is secured with a metal frame. Based on the pictures in figure 1, the glass is curved in at least one direction for an increased stability. The door opens from the inside with a traditional handle. The handle is directly connected to the lock mechanism. A handrail is attached in the glass for extra support for the operator.

Figure 1: Fendt 300 Vario
**APPENDIX 1 – MARKET ANALYSIS**

**Claas**
The door seen in figure 2 is frameless with only a sealing with a metal strip inside for strength and stability. Based on the pictures in figure 2, the glass is curved in two directions for a higher stability. The glass has a pretension in the upper left corner for increased seal. The glass is toughened and comes from Pilkington. The door opens from the outside with a handle similar to the handle Volvo CE has for the standard WLO door. There is at least one handrail inside of the cabin for support for the operator. This design is one of the most modern and innovative since there is no real frame.

![Figure 2: Claas Axos 340-310](image)

**Valtra**
The door seen in figure 3 and 4 consists of a sheet of glass with a metal frame and is curved in at least one direction for an increased stability. The handle (black u-shaped pipe) has a simple design that fulfills the need of closing the door from the inside. This handle operates as a handrail since its main purpose is to grab it, pull the door against the cab, and close the door. This handrail does not have an opening or locking mechanism. Valtra has a similar design as Fendt. The lock has a protecting shield so that the operator does not come in contact with the opening mechanism and open the door by mistake. The door opens from the outside with a handle similar to the one that Claas (figure 2) and Volvo CE have today for the standard WLO door.

![Figure 3: Valtra N163](image)  ![Figure 4: Valtra inside of door](image)
Lännen

Lännen Lundberg (figure 5) has a more old fashioned appearance with a glass door that is divided in multiple sections. The door is secured with a metal frame for each section.

Lännen (figure 6) has a different appearance compared with Lännen Lundberg. The door consists of solely one sheet of glass that is mounted in a metal frame.

Huddig

Huddig has a similar design of the doors as the ones from Valtra (figure 3 and 4) and Claas (figure 2). The door consists of a sheet of glass with a metal frame that surrounds the door. Pictures of machines from Huddig are seen in figure 7 and 8.

The door opens from the outside with a handle that is similar to the other companies (Volvo, Claas, Valtra, New Holland). The glass appears to be curved in at least one direction.
New Holland

The machine from New Holland has a door that is similar to Claas’s (figure 2). The door consists of a single sheet of glass without a frame. Instead, the door has a sealing with a metal strip inside that surrounds the glass sheet. The door opens from the outside with a handle that is similar to other companies (Huddig, Volvo, Claas, Valtra). Inside of the door is a longer handrail attached that leads into the inside handle. The glass is curved in at least one direction. Pictures of machines from New Holland are seen in figure 9 and 10.

Future trends
There appears to be some trends about the design of doors. The doors are appearing to:

- Be frameless
- Have a sealing with a metal strip acts as a frame
- Be solely in glass
- Have no splitting, meaning that the window will not be divided into several sections

Conclusion agriculture
Agricultural companies are trying new designs and they are not afraid of trying new ways of designs and technical solutions. The designs of the doors are becoming more glass inspired and have a more modern and softer look. The type of environment that tractors and similar products are operating in is in a way kinder compared to construction sites. Therefore, components of agricultural machines can be built in less robust materials in a greater extent.

The doors are becoming more and more frameless. Instead, there is often only a sheet of glass with a sealing with a metal strip inside of it. However, there are still a lot of different designs with frames but the door is mostly in one sheet (not divided into multiple sections), which gives a more modern and not so bulky impression. The handles for opening the door from the outside are similar in design.
Construction equipment companies and their products

**JCB**
The overall impression of the JCB machine, seen in figure 11, is that it is compact and quite bulky. The door however is slimmer and in a sheet of glass. The glass is secured with a frame that leads to a metal sheet that surrounds the rest of the glass. The outside handle has a different design compared to the agricultural machines. Based on figure 11, the glass may be curved in one direction.

![Figure 11: JCB Wheel Loader 406](image)

**CAT**
The door for the compact WLO from CAT (figure 12) is in line with the trend of a single sheet of glass that appears to be without a frame, but instead has a sealing that acts as a frame. The handle of the door is similar to doors for compact WLO’s from Volvo CE. Based on the picture in figure 12 the glass may be curved in one direction.

![Figure 12: CAT Compact Wheel Loaders 906H2](image)
APPENDIX 1 – MARKET ANALYSIS

John Deere

![John Deere 410K TC Backhoe Loader](image)

The machines from John Deere have doors where the glass is secured with a frame. The handle on the outside has a similar design as the handle on the standard door for the Volvo CE WLO. Some doors have glass sheets that are divided into two sections with a metal frame between the sections. Based on figure 13 the glass may not be curved.

LiuGong

![LiuGong Wheel Loader CLG820C and Backhoe Loader 766A (Perkins)](image)

The designs of the doors are similar to the ones from CAT. The WLO in figure 14 has a door where the glass is divided into two sections, and with a metal frame that surrounds the glass. The outer handle is similar to the handle on the standard door for the WLO at Volvo CE but is mounted in a different direction. Based on the picture of the WLO the glass may not be curved. The backhoe loader, seen to the right, in figure 14 has a door with a single sheet of glass. Based on the picture, the glass may be curved in at least one direction. This door also appears to have a metal frame around the glass.
Bosal Sekura

Bosal Sekura offers a different design of their products compared to the other companies. The doors have a single sheet of glass and are based on the figures 15, 16, 17 and 18 curved in at least one direction. The doors have mostly a pipe shaped frame that secures the glass. The handles on the outside have a different design and shape compared to the other companies. Figure 17 shows a door with a sliding door, which is rather unique. The outside handle on that door (figure 17) has also a different design compared to the others from Bosal Sekura. The handrails are connected to the lock mechanism and appear to include an inner handle in the same part.
Gehl
The door of the machine from Gehl has a modern look with a single sheet of glass. The door appears to have a sealant with a metal strip that acts as a frame. The outer handle is quite similar to the handle on the standard WLO door from Volvo CE, but is in another direction and is directly connected to the lock on the inside. On the inside is a handrail that appears to be in two directions. The handrail also appears to include the inner handle. Based on figure 19 the glass appears to be curved in at least one direction.

Figure 19: Gehl 340 Articulated Loader

Conclusion construction equipment
Based on the information above companies that offers construction equipment seems to want doors with more glass than before and doors that have solely one sheet of glass instead of multiple sections. So far, it is not as common to have frameless door as it is for companies that offer products within agriculture. However, some exceptions show that the trend is leaning against offering more doors that are frameless. The design of the outside handle seems to have a communal shape and is often similar to the handle for the standard WLO at Volvo CE.
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APPENDIX 2 – QUESTIONNAIRE RESPONSES

Johan Wiber
(Salesperson at Lantmännen Tractors) 2014-01-31 by telephone at 10.10 am

Regarding the machines from the companies Claas, Fendt and Valtra. The tractors are sound insulated. However, that is not just because of the door. The driver never drives with the door open because one does not want to get dust into the cabin. It was more common to drive with the door open before when the AC was not that well developed, but that is not necessary today. The glass door can break if, by some reason, the door has been opened and one is parking for example. If the door slams into something, it may of course break. When the tractor is needed for forestry, the glass can be switched to polycarbonate instead. The visibility is naturally better and that is one of the main reasons for choosing a door made in glass. However, the pane gets dirty just like any window. The door is experienced as safe and according to Wiberg drivers do not feel vulnerable sitting close to a glass door and are not seeing any problems or risks with that the door may break and one could possibly get glass shatter on oneself. has never heard any complaint about the door.

Åse Laurin
(Salesperson, Bergström Maskin) 2014-02-03 by e-mail:
Regarding WLO from JCB.

Q: The doors on the WLO from JCB are made in glass in a large extent (no frames/panels). Does it happen that the door/pane get damaged or breaks or is it not a common problem?

A: It happens but is not so common.

Q: How do your costumers experience the sound levels, is it experienced as sound insulated?

A: Today, the emphasis is very much on reducing noise levels inside the cabin so it only gets better. JCB has worked a lot with altering the cabin so that it will be quieter.

Q: How is the thermal insulation experienced? Is it often experienced to be too cold or hot?

A: The machines today have in the most cases climate control and then it is easy to regulate the heat. There is also a good outlet at the feet where many experiences that it is cold in many machines. There is also a good outlet on the panes so that these do not steam up.

Q: How is the door used in the work, i.e. is it used as another window that is used for the visibility? Is the visibility experienced as better by having a door made in a large amount of glass? Does the door often get so dirty that the visibility is impaired?

A: Our doors are entirely in glass to get the ultimate visibility. The door does not get any dirtier than other panes.

Q: Do the driver prefer to drive with the door closed or open? Under which circumstances does one want to drive with the door open?

A: Both, depending on what kind of work being done. If you have so called “ground-men” (operators outside the machine on the field, authors’ clarification) that the driver
APPENDIX 2 – QUESTIONNAIRE RESPONSES

needs to talk to the door is open, but many wants to keep the dirt outside the cabin so then you choose to close the door. It is hard to say which is more common.

Q: Is it experienced as easy to get in and out of the machine (open and close the door)? Is it considered to be easy, obvious and good grip/handles?

A: To get in and out is more or less the same in all machines. It works well to open and close the door, however JCB has choose to have a slight overpressure inside the cabin to prevent that dust and dirt gets in. This means that one needs to use a little more force when closing, but that becomes a habit that is appreciated in order to avoid the dirt.

Q: Is the door experienced as safe?

A: Yes.

Q: Any other opinions or complaints that you have heard?

A: No
APPENDIX 3 - REQUIREMENT SPECIFICATION

The requirement specification is confidential.

1.0 Manufacturing and assembly requirements

1.1 Water tightness

Water tightness shall be done according to technical regulation HUTB6001 Cab water test specification Version HUTB6001-04 describes test of complete cabs on machine types WLO, ART and EXC.

1.2 Air tightness


1.3 Reference Point System (RPS)

The glass door must be designed using RPS where:

- Y1, X4, Z6 shall be on the lower hinges mounting
- Y2 and X5 shall be on the upper hinges mounting
- Y3 shall be in a surface point on the profile in the region of the locking system.

1.4 Cost

The cost for the final product cannot exceed the cost for the standard door.

1.5 Ease of manufacture

Take DFM into account when designing door and including parts.

1.6 Ease of assembly

Take DFA into account when designing door and including parts.

2.0 Material requirements

2.1 Sealing

When choosing a sealing, firstly a communality sealing shall be chosen. If a common one is nonexistent, a model that already is in us in the Volvo CE range should be chosen.

2.2 Choice of material

Choice of material must be appropriate to the working environment door is used in.

3.0 Functionality requirements

3.1 Position of handle

Handle should be positioned in such a way that visibility through the door is not impaired.

3.2 Position of handrail

3.2.1 Handrail should be positioned in such a way that visibility through the door is not impaired.

3.2.2 It is important to try to have long handrails without attachment points on the middle so the operator doesn’t have to change grip so often.
APPENDIX 3 - REQUIREMENT SPECIFICATION

3.3 Three point grip

The standard states that the operator always shall have a three point grip i.e. always have support for two feet and one hand or two hands and one foot.

4.0 Ergonomic requirements

4.1 Handles

Handles should be ergonomically designed and positioned.

4.1.1 Handles should be easily accessed and operated from the chair.

4.1.2 Handles should be easily accessed and used from the steps outside the cabin.

4.2 Handrails

Handrails should be ergonomically designed and positioned.

4.2.1 Handrails for entering/exiting, and handrails exposed to on-road traffic, should have a reflective tape or paint, at least on a small part of its length.

4.2.2 Handrails should preferably be in a contrasting color against the background. When it is not realistic to meet the standard fully, it is important to design an entrance that is as ergonomic and safe as possible under the conditions. If we do that and are among the best in the market, we are probably safe from a legal point of view.

5.0 Door and handrails

5.1 The door must be applicable to the existing wheel loader cabs.

5.2 Handrails

5.2.1 All handrails must meet ISO 2867:2006 Earth-moving machinery — Access systems.

Summary of the requirement in ISO 2867:2006

- All handrails shall withstand 1 kN in worst direction without permanent deformation.
- Deformation from 1 kN load shall not exceed 80 mm.
- For a feeling of safety, the deflection from 1 kN load should not be over about 30 mm.

To define the material thickness and what material to use in handrails, there has to be a strength calculation.

5.2.1.1 Volvo rule: Handrails shall withstand 1.5 kN in positions and directions where heavy loads can be expected without permanent deformation. Fatigue from force of about 0.5 kN shall also be considered in those cases.

5.2.1.2 Diameter
APPENDIX 3 - REQUIREMENT SPECIFICATION

Minimum handrail diameter in the standard is 20 mm and recommended is 25 mm. In Volvo, we shall use 25 mm as much as possible. Thinner handrails shall only be used when space is limited.

5.4.5 Space around handrails

Space around handrails and handles is recommended to be 50 mm and minimum is 40 mm. It is not totally clear in the standard when it is applicable, but we use it on all handrails and controls that the operator grab.

5.4.5.1 Volvo rule: The space shall be 50 mm, except where it is impossible due to limited space. Distances down to 40 mm can be accepted in such cases.
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# EVALUATION OF EXISTING DOOR SOLUTIONS

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Concept 1 Whole door (figure 1)
The door is made entirely in glass without a frame, unlike the standard door. On the inside of the glass is a sealant attached with glue. The handrail is shaped in a continuous pipe that allows the user to use the handrail both for support when entering and exiting and to use it to close the door. The outer handle is connected to the handrail through the glass and hidden inside the handrail. This would increase the feeling of a glass door. The handrail is attached against the glass with either glue or screws. To get a door that is perceived as a complete glass door the number of details in the glass should be kept as low as possible. A thought was therefore to hide the outer handle and its lock wire inside the pipe frame. However, since the assembling of these parts involves screws and nuts that manually need to be positioned this suggestion is not feasible.

Concept 2 Whole door (figure 2)
This concept is a hybrid between the standard door and a complete glass door. Surrounding the glass edges is a pipe frame that is attached against the glass with either a track that glass can slide into or a clamp that is attached on the pipe frame that clamps the glass. The outer handle and locker could be attached directly into the pipe frame which would mean a clearer glass.

Concept 3 Whole door (figure 3)
In this concept the thought was to use the lower handle as an attachment point for the horizontal handrail to increase stability and saving cutouts in the glass.
Concept 4 Whole door (figure 4)
Concept 4 involves a partially framed door. The frame is around the lower and right edges. This is to get an increase in pretension in the upper right corner (seen from front side) in order to get a better seal against the cabin frame.

Concept 5 Whole door:
A new design of the handrails with a softer feeling than the straight handrails. The locker is directly attached to the outer handle and can be considered to be hidden by the outer handle. For this to work the door needs to be wider than the door opening so that the locker is in the same level as the locker parts on the cabin frame.

Concept 6 Whole door (figure 6)
This concept involves two handrails (one vertical and one horizontal) that are possibly welded together. The vertical handrail is attached in both of the hinges. The horizontal handrail is similar to the original with the inner handle hidden inside of the handrail. A cover is used to hide the lock wires etc. that the handles and locker are connected to.
Concept 7 Whole door (figure 7)
This concept shows an idea about a new design of the handrail. Instead of having a horizontal and vertical handrail an arc shaped handrail is suggested. The inner handle would be positioned in the arc itself. The outer handle is positioned in the straight part of the handrail. The lock wires would need to be flexible in order to follow the arc shape. The handles would be connected to the locker by an opening in the handrail. The parts of the locker are covered.

Concept 8 Whole door (figure 8)
This concept cover the thought of separating the horizontal and vertical handrail from each other. However the exact design has not been in focus here. The vertical handrail would be positioned at the left side (seen from front). The horizontal handrail would be needed to be shortened. In order to hide the lock wire from the inside handle the horizontal handrail would be elongated also vertical (formed like a T). The outer handles lock wire would also be hidden inside the vertical part of the horizontal handrail. The locker would possibly need to change position to the lower edge of the glass. This is to get the feeling of a glass door without parts that steals focus.

Concept 9 Whole door (figure 9)
To save space inside the cabin the glass does not need to be planar. Instead the glass could be an elongation of the cabin with walls, a top and a floor.

Concept 10 Whole door
Surrounding the glass is a pipe frame that can be split into two parts for easy assembling and the option to change the glass if needed. (No picture).
**Concept 1.1**
A weather strip that is glued against the frame. On the bottom of the frame (at the floor) is a larger “bump” that has the sealing attached to it. The thought of having this bump is because only having the sealing directly attached at the frame could mean that users walk on it. With the bump it is believed as the user would more likely step on the bump instead of the sealing. It is a bump shape since that would hopefully decrease the risk of tripping (instead of having a sharp edge). See figure 1.

![Figure 1: Concept 1.1](image1)

**Concept 1.2**
The sealing has the shape of a U and is glued against/surrounds the cabin frame. However, this is a suggestion that fast got rejected since the shape of the cabin frame makes this solution ineffective. See figure 2.

![Figure 2: Concept 1.2](image2)
Concept 1.3
This concept is combination of concept 1.1 and 1.2. A continuous sealing that is attached against the cabin frame with screws. The sealing does not surround the entire cabin frame and needs to be thicker at the bottom in order to tolerate people stepping on it. See figure 3.

Concept 2.2
This concept is the same as for 2.1 but the sealing is attached with screws instead of glue. (No picture).
### Evaluation of Door Concepts

**Project:** Glass Door - Volvo CE  
**Made by:** Josefin Hult  
**Date:** 2014-09-08

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**Concept:**

- Ref. 1:
  - 1: High solution
  - 1.1: Low solution
  - 1.2: Medium solution

- Conclusions:
  - 2 to 3: Acceptable
  - 0 to 1: Necessary improvement
  - +1 to +3: Excellent
  - -1 to -3: Poor

**Legend:**

- Seal on glass: A metal seal is used along the edge of the door sealing.
- Seal on frame: A metal seal is used on the frame.
- Seal on frame and glass: A metal seal is used on both the frame and glass.
- Seal on glass only: A metal seal is used only on the glass.
The combined concepts in phase 2 that are built on the concepts that were considered most suitable for the whole door and the sealing are shown below.

- Concept 1. The concept is seen in figure 1.

Figure 1: Concept 1.
• Concept 2. The concept is seen in figure 2.

Figure 2: Concept 2.

• Concept 3. The concept is seen in figure 3.

Figure 3: Concept 3.
• Concept 4. The concept is seen in figure 4.

![Figure 4: Concept 4.](image)

• Concept 5. The concept is seen in figure 5.

![Figure 5: Concept 5.](image)
Confidential
Confidential
Confidential
Confidential
Confidential
Confidential
Confidential
Confidential
Confidential
Confidential
Confidential
Confidential
APPENDIX 10 – BEND TABLE FOR HANDRAILS

The bend table is confidential.
APPENDIX 11 – Bills Of Materials (BOM)

The BOM-list is confidential.
APPENDIX 12 – CAD PHOTOS OF DOOR CONCEPT