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# Cargo Space Design for Sustainable, Urban Transport of Cold Goods

Re:Load, a Rollable Shelf Structure Solution for the Electric Vehicle Re:Volt:  
Optimized Utilization of the Cargo Space with Regards to Loading  
Capacity, Physical- and Cognitive Ergonomics

Master's Thesis in Industrial Design Engineering

**ALEXANDER MATTSSON & AMELIE NORDH**

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DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE  
CHALMERS UNIVERSITY OF TECHNOLOGY



MASTER'S THESIS 2022

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Department of Industrial and Materials Science  
*Division of Design & Human Factors*  
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ALEXANDER MATTSSON & AMELIE NORDH

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Supervisor: Olof Wranne, Department of Industrial and Materials Science  
Examiner: Olof Wranne, Department of Industrial and Materials Science

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Department of Industrial and Materials Science  
Division of Design & Human Factors  
Chalmers University of Technology  
SE-412 96 Gothenburg  
Telephone +46 31 772 1000

Cover: Visualization of Re:Load, a storage solution for the electric vehicle Re:Volt.

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## Abstract

The intention of the project was to design a storage solution for the cargo space part of the electric vehicle called Re:Volt that is under development by Clean Motion, to facilitate its use for the transport of groceries as part of last mile deliveries in an urban environment. Part of this was to determine the most suitable cooling technology and solution for the vehicle's cargo space.

Research was carried out of what operations within the current industry of last mile delivery of groceries looked like, to understand how different-sized vehicles were used to deliver different-sized orders to consumers within varying time spans. People with responsibility for operations within E-commerce of groceries at relevant companies operating within the industry were contacted and interviewed to understand their current operations and needs. The research concluded that Re:Volt, with some respective adjustments, could fit well for both quick commerce applications with delivery times of within an hour and planned deliveries with delivery times exceeding one hour.

Dometic Frigo DC2500 was the cooling solution chosen to offer an air temperature of 2–4°C in the cargo space of Re:Volt, supported by 30 mm thick polyurethane foam insulation panels to line the walls of the space. The final solution mainly consisted of a rollabe shelf unit that could be loaded with goods both outside and inside the cargo space of Re:Volt. It was named Re:Load, with a capacity of 36 standard paper bags for groceries intended to be stored at 2–4°C. Of the 36 bags, up to 16 of them could be replaced with a maximum of four insulated freezer boxes each containing a PCM block, which consequently allowed the storage of up to 12 smaller paper bags at a temperature of -18°C to -21°C. The final offering was a shelf storage solution that could be implemented into current operations of last mile delivery, that enabled a good interaction for the intended user with the goods in the cargo space regarding physical- and cognitive ergonomics.

The design of the cargo space of Re:Volt and the shelf solution Re:Load were deemed suitable to be used for either quick commerce or planned delivery applications. It could also result in the potential to shape and establish a new market segment for the food delivery industry where the gap between operations of quick commerce and planned deliveries would decrease. Alternatively, the vehicle could operate within the two areas of quick commerce and planned deliveries simultaneously.

*Keywords:* electric delivery vehicle, adjustable storage solution, refrigerated delivery vehicle, product development, last mile delivery, quick commerce, planned delivery



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# Definitions

Below are the definitions of some industry specific words and concepts.

<i>Quick Commerce</i>	Quick on-demand delivery, where the the order tends to be smaller and delivered within an hour of the order being placed.
<i>Planned Delivery</i>	Deliveries of 10+ orders that are scheduled to be delivered with the same vehicle on a pre-determined route, with a delivery time exceeding one hour.
<i>Unbroken Cold Chain</i>	The use of low temperature controlled areas throughout all steps of the supply chain to ensure product quality.
<i>Micro Distribution Center</i>	Centrally placed, smaller logistics center, generally used to redistribute cargo from one larger delivery vehicle into several smaller delivery vehicles.



# Contents

<b>Definitions</b>	<b>ix</b>
<b>List of Figures</b>	<b>xvii</b>
<b>List of Tables</b>	<b>xxiii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Background . . . . .	1
1.1.1 The Company Clean Motion . . . . .	1
1.1.2 The Vehicle Re:Volt . . . . .	2
1.2 Expectations from Clients . . . . .	3
1.3 Aim and Goal . . . . .	3
1.4 Objectives . . . . .	3
1.5 Demarcations . . . . .	3
<b>2 Theory</b>	<b>5</b>
2.1 Rules and Regulations related to Temperature for Transport in the Food Industry . . . . .	5
2.1.1 Pre-packed, Refrigerated Groceries . . . . .	5
2.1.2 Industry Guidelines: Handling, Storage and Transport of Cold and Frozen Groceries . . . . .	5
2.1.3 Temperature Requirements of Food Product Groups . . . . .	6
2.1.4 Regulations Related to Temperature Measuring and Storage of Data During Transport . . . . .	7
2.2 Rules and Regulations Related to Work Environment . . . . .	8
2.2.1 Ergonomics for the Prevention of Musculoskeletal Disorders . . . . .	8
2.2.2 Time Pressure as an Influencing Factor . . . . .	9
2.3 Cooling . . . . .	9
2.3.1 Broad Concepts of Cooling a Space . . . . .	9
2.3.1.1 Cooling Capacity vs Passive and Active Thermal Energy Loss . . . . .	9
2.3.1.2 Passive vs Active Cooling . . . . .	9
2.3.2 Active Cooling Systems . . . . .	10
2.3.2.1 Vapor Compression Cycle Cooling . . . . .	10
2.3.3 Passive Cooling Systems . . . . .	11
2.3.3.1 Passive Phase Change Materials (PCM) . . . . .	11
2.3.3.2 Active Eutectic Plates . . . . .	12

2.3.3.3	Dry-Ice . . . . .	14
2.3.4	Available Active Cooling Systems Offered by Dometic . . . . .	15
2.3.4.1	Frigo DC2500 . . . . .	15
2.3.4.2	ColdMachine . . . . .	17
2.4	Insulation . . . . .	18
2.4.1	Insulation Material: Polyurethane . . . . .	18
<b>3</b>	<b>Methods</b>	<b>21</b>
3.1	Structured Interview . . . . .	21
3.2	Semi-Structured Interview . . . . .	21
3.3	Observations . . . . .	21
3.4	HTA - Hierarchial Task Analysis . . . . .	22
3.5	REBA - Rapid Entire Body Assessment . . . . .	22
3.6	Affinity Diagram . . . . .	23
3.7	Personas . . . . .	23
3.8	Function Tree . . . . .	23
3.9	Weighted Criteria Matrix . . . . .	24
3.10	Concept Comparison Matrix . . . . .	24
3.11	Double Diamond Design Process . . . . .	25
<b>4</b>	<b>Procedures and Results: First Iteration</b>	<b>27</b>
4.1	Research Phase 1 . . . . .	27
4.1.1	Rules and Regulations related to Temperature for Transport in the Food Industry . . . . .	27
4.1.2	Rules and Regulations Related to Work Environment . . . . .	28
4.1.3	Understanding the Market Segment of Vehicles for last mile delivery of groceries . . . . .	28
4.1.3.1	Market Analysis of Current Delivery Vehicles of Dif- ferent Sizes . . . . .	28
4.1.3.2	Project Brief and Initial Group Discussion at Dometic	30
4.1.3.3	Re:Volt’s Market Segment and Use Case . . . . .	31
4.1.4	Understanding the Market Segment of Companies Operating Within Last Mile Delivery of Groceries . . . . .	32
4.1.4.1	Interview with Transport Manager for E-commerce Logistics Groceries . . . . .	32
4.1.4.2	Interview with Transport Manager for E-commerce Logistics Groceries Dagab Inköp & Logistik AB . . . . .	32
4.1.4.3	Five Online Video Observations of Food Delivery Processes . . . . .	33
4.1.4.4	Direct Contact with Business Managers at Clean Motion for Insights of Potential Customers’ Needs . . . . .	34
4.1.4.5	Current Packaging of Groceries . . . . .	34
4.1.5	User Studies . . . . .	35
4.1.5.1	Target User Group . . . . .	35
4.1.5.2	User Journeys . . . . .	36
4.1.5.3	Interview with Delivery Driver at Bzzt . . . . .	36
4.1.5.4	Direct Observation of an ICA Delivery Truck . . . . .	37

4.1.5.5	Three Direct Observations of a Mathem Delivery Truck	38
4.1.5.6	Personas . . . . .	41
4.1.5.7	HTA (Hierarchial Task Analysis) . . . . .	43
4.1.6	Cooling technology . . . . .	44
4.1.6.1	Factors in Cold Air Escaping From a Refrigerated Space . . . . .	44
4.1.6.2	First Expert Interview with Development Engineer with Cooling Technology Expertise at Dometic . . .	45
4.1.6.3	Second Expert Interview with Development Engineer with Cooling Technology Expertise at Dometic .	45
4.1.6.4	Group Discussion with Development Engineer and Two Business Managers . . . . .	46
4.1.7	Key Results from Research Phase 1 . . . . .	46
4.1.7.1	Affinity Diagram . . . . .	47
4.1.7.2	Intended Use Case for Re:Volt . . . . .	49
4.1.7.3	Function tree . . . . .	49
4.1.7.4	Adding Weights to the Six Main Part Functions . . .	51
4.1.7.5	Requirement list . . . . .	51
4.1.7.6	Choice of Cooling Technique: Refrigerated Space of 2°C–4°C . . . . .	54
4.2	Ideation Phase 1 . . . . .	54
4.2.1	Ideation During Research Phase 1 . . . . .	54
4.2.2	Function Tree Second Iteration . . . . .	56
4.2.3	Ideation and Sketching Session for Part Solutions . . . . .	57
4.2.3.1	Part Solutions to Offer Easy Loading, Ensured Product Quality and Easy Unloading . . . . .	58
4.2.3.2	Number of Shelves in the Cargo Space . . . . .	58
4.2.4	Quick Prototyping . . . . .	60
4.2.4.1	Small Scale Cardboard Prototyping . . . . .	60
4.2.5	Large Scale Re:Volt Mock-up . . . . .	60
4.2.6	Exploring and Choosing an Overall Concept Direction . . . .	61
4.2.6.1	Concept Direction 1: Permanently Installed Shelf Structure . . . . .	62
4.2.6.2	Concept Direction 2: Movable Shelf Structure . . . .	63
4.2.6.3	Concept Direction 3: An empty Cargo Space . . . .	63
4.2.6.4	Choosing a Concept Direction . . . . .	64
4.2.7	Development of Concept Direction 2: Movable Shelf Structure	65
4.2.7.1	CAD Representation of Re:Volt . . . . .	65
4.2.7.2	Ideation of the Shelf Structure Design . . . . .	66
4.2.8	Resulting Three Concepts from Ideation Phase 1 . . . . .	67
4.2.8.1	Concept A: Twins . . . . .	67
4.2.8.2	Concept B: The Unit . . . . .	68
4.2.8.3	Concept C: Semi Static . . . . .	69
4.3	Evaluation Phase 1 . . . . .	70
4.3.1	Ergonomic Evaluation of Re:Volt’s Initial Side Panels . . . . .	70
4.3.2	Half Time Presentation for Clean Motion . . . . .	72

4.3.3	Feedback Dialogue with Operations Manager at Picsmart . . .	73
4.3.4	Concept Comparison Matrix . . . . .	74
4.3.5	Summarized Results of Evaluation Phase 1 . . . . .	76
<b>5</b>	<b>Procedures and Results: Second Iteration</b>	<b>79</b>
5.1	Research Phase 2 . . . . .	79
5.1.1	Continued Understanding of the Market Segment of Companies Operating Within Last Mile Delivery of Groceries . . . .	79
5.1.1.1	First Interview with an Operations Manager at Picsmart . . . . .	79
5.1.1.2	Second Interview with Picsmart . . . . .	80
5.1.2	Storing Frozen Goods During Delivery . . . . .	80
5.1.2.1	Dometic ColdMachine VD-16 (when used with ColdMachine CU-96) . . . . .	81
5.1.2.2	Freezer Alternative: Active Freezer . . . . .	81
5.1.2.3	Passive PCM . . . . .	82
5.1.2.4	Interview with Company Representative from iFoodbag . . . . .	83
5.1.2.5	Dry-ice . . . . .	84
5.1.2.6	Freezer Alternative: Passive Freezer . . . . .	84
5.1.3	Doors . . . . .	85
5.1.3.1	Insights from Development Engineer with Cooling Technology Expertise . . . . .	85
5.1.3.2	Retention of Cold Air During Door Openings . . . .	85
5.1.3.3	Online Research and Observations of Different Door Variations . . . . .	86
5.2	Ideation Phase 2 . . . . .	88
5.2.1	Starting Point for Ideation Phase 2 . . . . .	88
5.2.2	Offering of a Freezer Space . . . . .	89
5.2.3	Interaction with Physical Large Scale Mock-up . . . . .	90
5.2.3.1	Unloading of a Paper Bag from the Upper and Lower Shelf . . . . .	91
5.2.3.2	Accessing the Content of the Freezer Solution, Two Versions of an alvobox . . . . .	92
5.2.4	Direct Access to Paper Bags . . . . .	94
5.2.5	Mid-Concept Ideation Phase 2 . . . . .	96
5.2.6	Internal Walls' Positioning and the Effect on Order Capacity .	96
5.2.7	Revisiting Extendable Shelves . . . . .	98
5.2.8	Separating and Securing Orders . . . . .	99
5.2.9	Organisation of Orders . . . . .	101
5.2.9.1	Physical Test of Direction of Paper Bags on Upper Shelf . . . . .	101
5.2.9.2	Incorporation of a Middle Divider to Support Organisation of Orders and User Interaction Related to Shoulder Position . . . . .	103

5.2.9.3	Visualisation and Conceptualization of the Organi- sation of Paper Bags on the Upper Shelf . . . . .	105
5.2.10	Doors and Air Flow Blockage . . . . .	107
5.2.11	Insulation and Geometry of Inner Wheel Houses . . . . .	109
5.2.12	Additional Supportive Elements . . . . .	111
5.2.12.1	Supportive Function: Offer Zone for Temperature Sensitive Products . . . . .	111
5.2.12.2	Supportive Function: Having Cleaning Supplies Avail- able Inside Re:Volt . . . . .	112
5.2.12.3	Supportive Function: Support Delivery to Door . . .	112
5.2.12.4	Step Stool . . . . .	112
5.2.13	Final Concept . . . . .	113
5.3	Evaluation Phase 2 . . . . .	114
5.3.1	Mid-Concept Concept Evaluation with Picsmart . . . . .	114
5.3.2	Comparing the Final Concept to the Requirements Lists . . .	115
<b>6</b>	<b>Final Product</b>	<b>117</b>
6.1	Use Case Scenario Examples . . . . .	119
6.1.1	Implemented for Quick Commerce . . . . .	120
6.1.2	Implemented for Planned Deliveries . . . . .	121
6.2	Detailed Explanations of Re:Load’s Parts . . . . .	122
6.2.1	Metal Main Frame . . . . .	122
6.2.2	Extendable Upper Shelves . . . . .	123
6.2.3	Air Flow Blocker . . . . .	124
6.2.4	Dividers . . . . .	125
6.2.5	Pull-out Bottom Shelves . . . . .	126
6.2.6	Freezer Space: Alvoboxes . . . . .	128
6.2.6.1	Main Configuration . . . . .	129
6.2.6.2	Alternative Configurations . . . . .	130
6.2.7	Transportation Dolly . . . . .	131
6.3	Other Design Elements Part of the Cargo Space . . . . .	133
6.3.1	Insulation . . . . .	133
6.3.2	Doors to the Cargo Space . . . . .	133
6.3.3	Compartments Over the Wheelhouses . . . . .	134
<b>7</b>	<b>Discussion</b>	<b>135</b>
7.1	The Success of the Design . . . . .	135
7.1.1	Comparison of Solution Against Use Cases and Market Segment	135
7.1.2	The Optimal Use Case and Market Segment . . . . .	136
7.1.3	Prevention and Recovery of Potential User Errors . . . . .	136
7.2	The Involvement of Different Stakeholders in the Project . . . . .	137
7.3	Conflicting Needs and Requirements . . . . .	138
7.4	Credibility of Sources and References . . . . .	139
7.4.1	Potential Biases . . . . .	139
7.4.2	The Considered Rules and Regulations . . . . .	139
7.5	Ethics . . . . .	140
7.5.1	Designing For the Intended Users . . . . .	140

7.5.2	Advantageous Height Characteristics of the User . . . . .	140
7.6	Sustainability Aspects . . . . .	141
7.6.1	Re:Volt as a Delivery Vehicle in an Urban Environment . . . . .	141
7.6.2	Reduce Food Waste Part of The Last Mile Delivery . . . . .	141
7.6.3	Single Use Paper Bags . . . . .	142
7.6.4	Energy Loss . . . . .	143
7.6.5	Battery Usage . . . . .	143
7.7	Future Research . . . . .	143
<b>8</b>	<b>Conclusion</b>	<b>145</b>
	<b>References</b>	<b>147</b>
<b>A</b>	<b>Interviews</b>	<b>I</b>
A.1	Interview Answers from E-Commerce Transport Manager . . . . .	II
A.2	Interview Answers from E-Commerce Transport Manager Dagab . . . . .	IV
A.3	Interview Answers from Bzzt . . . . .	VI
A.4	First Interview with a Development Engineer at Dometic . . . . .	VII
A.5	Second Interview with a Development Engineer at Dometic . . . . .	IX
A.6	Interview with an Operations Manager at Picsmart . . . . .	XI
A.7	Interview with a Company Representative from iFoodbag . . . . .	XI
<b>B</b>	<b>Discussions Regarding Cooling and Freezing Technology</b>	<b>XIII</b>
B.1	Cooling Technology Alternatives . . . . .	XIV
B.2	Freezer Alternatives . . . . .	XVI

# List of Figures

1.1	The design of Re:Volt at the start of this project, from Clean Motion (2022).	2
2.1	Vapor compression cycle with pressure and enthalpy values for R134a, from Hundy, Trott, and Welch (2016).	10
2.2	An example installation of active eutectic plates in a cargo space, from IndiaMART (n.d.).	13
2.3	An example showing the impact of door openings on the temperature of a cargo space with an installed active eutectic plate as the cooling system, from PLUS (n.d.).	14
2.4	Case Frigo DC2500.	16
2.5	The cross section of two PUL-panels used for insulation, from Topolo (n.d.).	19
3.1	Example of a weighted criteria matrix.	24
3.2	Example of a concept comparison matrix.	25
3.3	Visualisation of a double diamond design process, from Prd (n.d.)	25
4.1	Transport alternatives for cooled groceries, with the cargo space ranging from extra small to extra large.	29
4.2	A map that shows different companies' delivery times, order capacity, utilized vehicles, and estimated delivery radii.	31
4.3	A selection of screenshots from a video uploaded to YouTube in 2015 by Mat.se.	33
4.4	Observed paper bag sizes, from left to right being: ICA.se, Mathem, Hellofresh, Coop, Picmart.	34
4.5	Dimensions of a bag that was used in CAD software during concept creation.	35
4.6	Clean motions first smaller, electric delivery vehicle called Zbee, from Motorzest (2016)	37
4.7	Photos taken of ICA's delivery truck and cooling boxes, along with their hand computer application and packed grocery bags.	37
4.8	Photos from a Mathem delivery, which shows a non-ergonomic position along with three bags being carried by the courier.	39
4.9	Photo of a Mathem truck (left) with a sketch of what the observed cargo space looked like (right).	40

4.10	Photos of how Mathem distributed different types of food in different bags, along with an illustration of a tool that was being used to pull plastic boxes inside of the truck. . . . .	41
4.11	Persona 1. . . . .	42
4.12	Persona 2. . . . .	42
4.13	Persona 3. . . . .	43
4.14	HTA of users interacting with the cargo space, performing the main task of home delivery of groceries. . . . .	44
4.15	Affinity diagram. . . . .	47
4.16	Function tree. . . . .	50
4.17	Tables that showcase the weight of different functions. . . . .	51
4.18	About half of the sketches and notes created during the first research phase, following the chronological course of the phase. . . . .	55
4.19	Updated function tree, second iteration. . . . .	57
4.20	Comparison of how two or three levels of shelves carrying paper bags would fit inside the cargo space of Re:Volt. . . . .	59
4.21	Smaller cardboard mock-up of Re:Volt and a separate transportation dolly to support loading and unloading of the larger shelf unit. . . . .	60
4.22	A quick 1:1 mock-up of the height and width of Re:Volt’s cargo space, the picture on the left representing the length of the cargo space and the picture to the right representing the floor height, the total height and the width of the cargo space. . . . .	61
4.23	Three different concept directions. . . . .	61
4.24	Concept direction: Permanently installed shelf structure. . . . .	62
4.25	Concept direction: Movable shelf structure. . . . .	63
4.26	Concept direction: Empty space. . . . .	64
4.27	Simplified CAD model of Re:Volt, including goods in the form of bags. . . . .	65
4.28	Sketches of different partitions inside the cargo space of Re:Volt as well as possible shelf structures. . . . .	66
4.29	Sketches using the CAD representation of Re:Volt filled with cargo in the form of paper bags as support. . . . .	67
4.30	Concept A. . . . .	68
4.31	Concept A: pallet variation. . . . .	68
4.32	Concept B. . . . .	69
4.33	Concept C. . . . .	70
4.34	The initial design of Re:Volt with static, lower side panels visualized in green. . . . .	71
4.35	Two REBA analysis conducted on a scenario that could occur where the user reaches in to collect some goods from the cargo space, using a simple 1:1 scale mock-up of Re:Volt’s side panel and side opening. . . . .	72
4.36	The tree concepts, presented to people at Clean Motion. . . . .	73
4.37	Concept comparison matrix of the three concepts being results of Ideation Phase 1. . . . .	75
4.38	Resulting concept based on feedback from Clean Motion and a concept comparison matrix. . . . .	77

5.1	Overview of the market study of insulated boxes utilizing passive PCM for cooling, freezer temperatures, from Polibox (n.d.); iFoodbag) (n.d.); Dometic Group (n.d.-a); Vakava Technologies (2022). . . . .	83
5.2	General doors. . . . .	86
5.3	Different doors to vehicles. . . . .	87
5.4	Different doors to a cooled cargo space. . . . .	87
5.5	The concept acting as a starting point for Ideation Phase 2. . . . .	89
5.6	Exploration of different concepts for offering a freezer solution. . . . .	90
5.7	Photos of the large and small alvobox offered by iFoodbag. . . . .	90
5.8	1:1 scale mock-up of Re:Volt. . . . .	91
5.9	Illustrations of how people of different height (about 150 cm, 172 cm, 180 cm and 191 cm) handle different situations of lifting a paper bag during unloading. . . . .	92
5.10	Usability testing with a large alvobox from iFoodbag. . . . .	93
5.11	Usability testing with a small alvobox from iFoodbag. . . . .	94
5.12	CAD visualising a shelf structure where the upper shelf is foldable. . . . .	94
5.13	Sketches in combination with CAD showing a pull-out shelf systems part of the lower shelf carrying a freezer box or paper bags. . . . .	95
5.14	Mid-phase concept, consisting of a movable shelf unit with four pull-out bottom shelves. . . . .	96
5.15	Difference in capacity from small and large concept. . . . .	97
5.16	Visualisation of necessary elongation of Re:Volt. . . . .	98
5.17	Usability testing of an extendable upper shelf. . . . .	99
5.18	Extendable shelves part of the upper shelf in the shelf structure. . . . .	99
5.19	Sketches for separation and segmentation of orders. . . . .	100
5.20	Sketches of different ways to prevent bags from sliding around during transport or to fall off the shelf during loading, transport of unloading. . . . .	101
5.21	Visualisations of tests of the lifting situation during unloading from the side of Re:Volt with paper bags placed on the upper shelf, parallel to the driving direction of Re:Volt. . . . .	102
5.22	Visualisations of tests of the lifting situation during unloading from the side of Re:Volt with paper bags placed on the upper shelf, perpendicular to the driving direction of Re:Volt. . . . .	103
5.23	Physical test of implementing four and five rows of paper bags on the upper shelf together with a full scale mock-up of Re:Volt and a representation of the shelf structure concept with similar dimensions. . . . .	104
5.24	Physical test and overlaid sketches to visualise the impact of paper bag placement on shoulder position during unloading from the upper shelf, the test person being 180 cm tall. . . . .	104
5.25	Physical test and overlaid sketches to visualise the implementation of a divider in the middle of the upper shelf, seen from the back of the cargo space. . . . .	105
5.26	Visualization of how bags would be placed on the upper shelf of the concept if they were placed perpendicular to Re:Volt's driving direction at the base upper shelf and placed parallel to the driving direction on the two extendable shelves. . . . .	106

5.27	Visualization of how bags would be placed on the upper shelf of the concept if they were all placed parallel to Re:Volt’s driving direction at both the base upper shelf on the two extendable shelves. . . . .	107
5.28	Door concept for the cargo space of Re:Volt, enabling access to cargo held by the shelf structure concept. . . . .	108
5.29	Air flow circulation inside of the cargo space of Re:Volt. . . . .	108
5.30	Concept for implementing air flow blockers to reduce active thermal energy loss of cooled air when a door to the cargo space of Re:Volt is opened, with a visualisation of how the air circulation can be seen as intact when the cargo space is fully closed by making all shelves have a net structure. . . . .	109
5.31	Rear edge of the cargo space shaped like a large chamfer, affecting the design and placement of the insulating panels part of insulating the cargo space. . . . .	110
5.32	Illustration over the halved extendable shelves at the sides of the shelf unit, as a result from the taller wheelhouses. . . . .	111
5.33	Visualization of the final concept. . . . .	114
6.1	Visualization of a man pushing Re:Load into Re:Volt (left), and a woman opening an alvobox (right). . . . .	117
6.2	Rendering of an alvobox that has been pulled out from the rear of Re:Volt. . . . .	118
6.3	Rendering of an opened side door of Re:Volt, showing the upper extendable shelf in a pulled out position. . . . .	118
6.4	Rendering of Re:Volt with one side door and both rear doors opened, with three lower shelves in extended positions. . . . .	119
6.5	Rendering of Re:Volt that showcases the compartment located above one of the wheelhouses. . . . .	119
6.6	Metal main frame part of Re:Load. . . . .	123
6.7	Extendable upper shelves. . . . .	124
6.8	Extendable upper shelves with paper bags. . . . .	124
6.9	Air flow blocker. . . . .	125
6.10	Dividers to secure and separate orders on the upper shelf of the shelf unit. . . . .	126
6.11	Pull-out bottom shelves. . . . .	127
6.12	Lower shelf with telescopic rails. . . . .	127
6.13	Pull-out bottom shelf carrying four standard paper bags (left), and a pull-out bottom shelf carrying an alvobox (right). . . . .	128
6.14	Illustration of how the alvobox can be opened during a delivery (top) and a sequence of how the PCM block is inserted into the lid of an alvobox. . . . .	129
6.15	Main configuration of alvoboxes and bags on the lower shelf of Re:Load. . . . .	130
6.16	Different amounts of alvoboxes loaded on the bottom shelves of Re:Load. . . . .	131
6.17	An empty transportation dolly (left) and a fully loaded transportation dolly (right). . . . .	131
6.18	The manual locking mechanism at the front of the transportation dolly. . . . .	132

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6.19	A fully loaded Re:Load pushed into the cargo space using the transportation dolly. . . . .	132
6.20	Insulation panel structure inside of Re:Volt's cargo space. . . . .	133
6.21	Doors for a version of Re:Volt that is designed with a cooled cargo space. . . . .	134
6.22	Storage compartments located above the wheelhouses in Re:Volt, accessed from the sides of the cargo space. . . . .	134



# List of Tables

4.1	Cooling requirements. . . . .	52
4.2	Insulation requirements. . . . .	52
4.3	Physical space requirements. . . . .	53
4.4	Order requirements. . . . .	53
4.5	Physical ergonomics requirements. . . . .	53
4.6	Administrative requirements. . . . .	54
5.1	Evaluation of how the final concept met the requirements, divided into six categories. . . . .	116



# 1

## Introduction

The introduction chapter describes the background, goal and aim of the project, along the companies in question. It also explains objectives to reach the goal, and lastly demarcations that describe areas that were left out from the project.

### 1.1 Background

The company Clean Motion was developing a three wheeled electric vehicle meant to go into production during late 2022. This vehicle was throughout this project called Re:Volt, being equipped with an electric powertrain and a solar panel that could support the internal battery. A use case for this vehicle was that it could be used as a part of a vehicle fleet for cargo transport within cities, covering the so called ‘last mile delivery’ in urban environments.

A collaborative effort was made with Clean Motion and another company named Dometic, that develops and produces cooling technology and off-the-shelf products, to develop a solution suitable for sustainable, urban transport of cold goods such as groceries. The development of such a solution had the potential of improving the working environment for couriers, by contributing to a better working situation in comparison to current solutions seen in the industry of last mile delivery of groceries, in regards to physical- and cognitive ergonomics. It could also benefit the end customers by ensuring a high product quality of groceries, and finally companies that could have potential interests in such a solution, by selling it as a package deal that would not require custom configuration.

#### 1.1.1 The Company Clean Motion

Clean Motion was founded in 2010 in the Gothenburg area, keeping the focus over the years of providing sustainable vehicles for urban areas, keeping energy and resource efficiency as central elements. The first vehicle put into production by Clean Motion is called Zbee. This vehicle has since been developed into a few versions, offering both person and cargo transport for shorter distances. Re:Volt is the second vehicle being developed by Clean Motion to be put into production, estimated to the end of 2022 (Clean Motion, n.d.-a).

### 1.1.2 The Vehicle Re:Volt

Re:Volt, a three-wheeled electric vehicle was developed intended to be used for last mile delivery, see Figure 1.1. The development of Re:Volt was in its final stages of development during the first half of 2022, set to start commercial pilots at the end of 2022. With the aim to be energy efficient, sustainable and light weight. The initially targeted market was seen to be Europe, aiming to covering a global market with time.

The vehicle was mainly planned to be registered as a moped with a capped speed of 45 km/h. In its most basic version, Re:Volt was estimated to weigh around 250–300 kg, with an cargo capacity of 2.5 m<sup>3</sup> at the initial phase of this project. The total vehicle weight when being fully loaded was estimated to be 700 kg (Clean Motion, n.d.-b), and the largest battery capacity offered was set to 10 kWh. With the vehicle being fully loaded up to the total weight of 700 kg, the vehicle was estimated to have a power consumption of 68 Wh per km. Depending on the charging solution, the charging time was estimated to be between 2–8 hours (W. Collings, personal communication, 2022).



**Figure 1.1:** The design of Re:Volt at the start of this project, from Clean Motion (2022).

Technical details such as exact measurements of the vehicle were not set in the beginning of the project, but got more defined as the project went on. Therefore, solutions and concepts were adapted to updated dimensions at several times throughout the project.

## 1.2 Expectations from Clients

According to William Collings, director of electric vehicle technology at Clean Motion, it was expected of the project to deliver some sort of solution covering the cargo space of the vehicle Re:Volt, being optimized when it comes to its usability, weight, cost, size, and insulation effectiveness and would work in theory. Meaning, the result did not have to consist of a physical or digital model. Dometic's current effort into development regarding mobile deliveries motivated them to see their involvement as a way to gain new insights for potential implementations for their products.

## 1.3 Aim and Goal

The aim was to work together with Clean Motion with support from Dometic to design a suitable variant of the cargo space of Re:Volt. The goal was to enable a sustainable, user friendly, adjustable and efficient alternative for last mile delivery, as part of urban transportation of groceries covering dry, refrigerated and frozen goods, using the electric vehicle Re:Volt. A part of this aim was also to strive towards utilizing already existing solutions as part of the design when suitable and possible.

## 1.4 Objectives

- Create an user friendly interaction with regards to the physical- and cognitive ergonomics of the user, with the cargo space and the storage solution within it as well as goods part of it.
- Minimize thermal energy loss of the cargo space.
- The cooling solution should be compatible with the energy carrying solutions currently being available in Re:Volt.
- The focus should be on home delivery of groceries in an urban environment, using the vehicle Re:Volt.
- Minimize the weight of the cooling solution and storage walls, without compromising strength and energy efficiency.
- Effectively optimize the order capacity of the cargo space volume, without compromising ergonomics and user friendliness of the solution.
- Minimize the production cost of the final solution.
- The physical design of the cargo space should be able to adapt to different customers' requirements, e.g., climate factors such as temperature zones as well as size of goods.

## 1.5 Demarcations

- Large batch deliveries to stores and from stores were not addressed.
- The cooling of other products than groceries was not considered.
- Handling of hot food was not considered.

## 1. Introduction

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- Standardized material for insulation will be utilized, commonly used in the refrigeration industry.
- The area outside of the cargo space in Re:Volt, such as the drivers cabin, was not factored in.
- The project only considered the physical design of the final solution.
- The final solution did not have to propose any type of physical nor digital solution that aided last mile delivery companies in where to place orders while loading, and no ways to verify those same orders while unloading.
- Individuals that ordered groceries were not taken into consideration. Focus was on the customer, referring to the companies responsible for the delivery as well as the users, referring to the personnel interacting with the cold goods throughout the delivery process.
- Active cooling systems covering products- and technology from other companies than Dometic were not factored into this project.
- Actors within the last mile delivery industry that were located outside of Sweden were not taken into consideration.

# 2

## Theory

The theory chapter describes different rules and regulations regarding how food can and should be stored during transportation, some issues that can surface with home delivery of food as well as different cooling techniques and insulation.

### **2.1 Rules and Regulations related to Temperature for Transport in the Food Industry**

This section was mainly based on a literature study of a document published by the Swedish Food Retailers Federation as well as additional documentation from the Swedish Food Agency and the Swedish Food Federation. According to the president and vice president of this Council for Cold-and Frozen Chain in Sweden (see section 4.1.1), the legislation and regulations for vehicles that are smaller than light duty trucks is lacking regarding transport of cold goods. With this as a basis, the decision was made to adhere to rules and regulations targeting light- and heavy duty trucks in areas related to the transportation of groceries covering dry, refrigerated and frozen products.

#### **2.1.1 Pre-packed, Refrigerated Groceries**

Refrigerated groceries is food to be stored in a temperature below room temperature. (Swedish Food Retailers Federation, 2021, p. 71).

The cold chain is not allowed to be broken, according to Regulation (EC) No 852/2004 of the European Parliament of the Council of 29 April 2004 on the hygiene of groceries. In addition to this, the temperature stated on the packaging has to be maintained. If the storage temperature of a product is below room temperature, it is required by law to be stated clearly on the packaging of the product (Söderqvist, 2016).

#### **2.1.2 Industry Guidelines: Handling, Storage and Transport of Cold and Frozen Groceries**

Swedish Food Retailers Federation (2021) is a collection of industry guidelines, based on regulations and common practice in regards to temperature control during storage and transport of cold and frozen groceries in Sweden. Targeting the flow of goods

from the producer to the store/restaurant/E-commerce consumer within Sweden.

An overarching regulation in relation to the temperature of handling, storage and transport of cold and frozen groceries is that it should ensure any health risk is avoided. Additionally, consider minimizing the risk of an affected product quality food waste as well as environmental and economical factors (Swedish Food Retailers Federation, 2021).

The main areas of consideration related to this are the temperature requirements for different groups of products, the usage of a temperature reserve and variables affecting the cold retention such as a co-storage and similar as well as regulations around air circulation and temperature measuring. Air humidity is not considered for this more temporary storing of groceries, such as during transport or related handling. (Swedish Food Retailers Federation, 2021).

### **2.1.3 Temperature Requirements of Food Product Groups**

The general rule is that the temperature requirements of the product should be clearly marked on the packaging, and satisfactorily followed throughout the transport stages (Söderqvist, 2016).

Another commonly adapted practice by the industry responsible for the handling, storage and transport of cold as well as frozen groceries is to utilize a temperature reserve. In practice, this results in an aim of keeping the product temperature  $2^{\circ}\text{C}$  below the temperature set regulated by law for refrigerated products and  $2^{\circ}\text{C}$ – $7^{\circ}\text{C}$  below the temperature set regulated by law for frozen products. This is seen as necessary in order to keep product temperature within an acceptable range, while enabling some temporary storage and handling outside of temperature-regulated areas (Swedish Food Retailers Federation, 2021, p. 13)

#### **Deep frozen food**

The definition of quick frozen products, also called deep frozen products, are products being rapidly frozen to a temperature of  $-18^{\circ}\text{C}$  or below. This does not include ice-cream products (Söderqvist, 2016, p. 106). Deep frozen products together with ice-cream products are also commonly referred to as frozen products.

Deep frozen food is never to exceed the temperature of  $-18^{\circ}\text{C}$  (Swedish Food Retailers Federation, 2021, p. 14). It is seen as acceptable that deep frozen food, except for ice-cream products, might have a temporary increase of product temperature to a maximum of  $-15^{\circ}\text{C}$  during for example transport. Ice-cream products are expected to always hold a product temperature of a maximum of  $-18^{\circ}\text{C}$  (Swedish Food Retailers Federation, 2021, p. 26).

#### **Products of animal origin**

The handling and temperature of cooled products of animal origin is more strictly regulated, related to the food safety of the product (Swedish Food Retailers Federation, 2021, p. 14). For minced meat, the maximum temperature of the product is set to 2°C. The air temperature can temporarily, for example during shorter transports, be up to 4°C (Swedish Food Retailers Federation, 2021, p. 27).

## Vegetables

Many fruit and vegetables should be stored at low temperatures ranging from 0°C–12°C in order to slow down their metabolic and transpiration (water loss from produce) rates (Gast, 1986). Gast (1986) states that transpiration rates can be slowed down by having a high humidity relative to the produce's water content, low air velocity and low temperatures. It is also mentioned that it is impossible to make a single recommendation of how to store all fruits and vegetables, but a general rule for cool-season crops and vegetables is 0°C–1,7°C, and 7,2°C–12°C for warm season crops. There are also fruits and vegetables that have an optimal storage temperature above 12°C, and a mix of 18 different ones were mentioned in the article by Gast (1986). Moreover, 16 out of 16 commonly grown fruits had an optimum storage temperature of about 0°C, and 44 of 68 common vegetables also had an optimum storage temperature of 0°C. The remaining 24 different vegetables had ranging optimum storage temperatures from 0°C–21°C. Freezing injury can occur in in both fruits and vegetables, but some can handle it better than others. Some produce can get damaged after a single time being frozen, whilst others can be frozen and thawed repeatedly (Gast, 1986). An important note is that the article described optimum conditions and temperatures for storing fruits and vegetables the longest possible duration. It did not mention how produce would be affected during shorter time frames of e.g. 1–3 hours, which is relevant in this project, see section 4.1.3.3.

Swedish Food Retailers Federation (2021, p. 68) describe the topic in a similar manner. They state that most produce can be sensitive to variations in temperature and drafts, and that it can be categorized into warm vegetables/fruits (>8°C) and cold vegetables/fruits (<8°C) (Swedish Food Retailers Federation, 2021, p. 68). There are no detailed regulations of temperature in relation to fruits and vegetables, other than the general rule of never compromising the food safety or quality of some product. It is seen as acceptable to store vegetables, being more sensitive, together with other products for a short period of time during transport (Swedish Food Retailers Federation, 2021, p. 26).

### 2.1.4 Regulations Related to Temperature Measuring and Storage of Data During Transport

All cargo spaces used for transport of food are defined as food business establishments, and are thus required to fulfill all requirements of one (Swedish Food Retailers Federation, 2021, p. 44). The main points of this are that the space is to be insulated, being designed to minimize thermal energy loss, equipped with a refrigeration

unit and an air circulation unit to keep a stable product temperature as well as measuring equipment to continuously measure the air temperature of the cargo space (Swedish Food Retailers Federation, 2021, p. 45). This data of measurements of air temperature during transport is to be stored and accessible at request for at least 12 months (Swedish Food Retailers Federation, 2021, p. 15). Permanently installed measuring devices for air temperature in the cargo space is recommended to be equipped with an alarm to flag for deviations in the air temperature (Swedish Food Retailers Federation, 2021, p. 44).

The carrier is responsible for the air temperature of the cargo space of the vehicle used for transport of cold groceries (Swedish Food Retailers Federation, 2021, p. 40).

## 2.2 Rules and Regulations Related to Work Environment

This section was mainly based on a literature study of work law and regulation regarding manual handling from The Swedish Work Environment Authority (2020). The main areas of concern connected to this is seen as heavy lifts, carrying heavier loads, pushing and dragging of objects. An additional area covered is time pressure as an influencing factor. The general guideline is that manual labour should be limited when possible (The Swedish Work Environment Authority, 2020).

### 2.2.1 Ergonomics for the Prevention of Musculoskeletal Disorders

Swedish regulations on the area of ergonomics for the prevention of musculoskeletal disorders are gathered in the code of statute AFS 2012:2 (The Swedish Work Environment Authority, 2019). Several parts are bringing attention to relevant factors to consider as risks that could result in injuries related to manual handling. Some of them are identified as especially relevant to pay attention to in the project.

#### *Properties of the load*

One factor seen as a risk for injury is if the placement of the load is requiring the load being handled while being at a distance from the body of the individual affected (The Swedish Work Environment Authority, 2019). It is seen as unsuitable to handle loads over 15 kg in these instances (The Swedish Work Environment Authority, 2020). Another aspect to pay attention to is if the load is being ungainly to handle or more difficult to get a good grip of (The Swedish Work Environment Authority, 2019).

#### *Physical exertion*

It can be seen as a risk for injury if the physical exertion of manually handling the load is overly strenuous (The Swedish Work Environment Authority, 2020). In addition, manual lifts of loads weighting over 25kg should generally not occur. Lastly, another risk factor for injury is if the physical exertion is performed through twisting

the torso (The Swedish Work Environment Authority, 2019).

#### *Work environment design*

The design of the work environment can pose a risk for injury if it hinders the individual to handle the load in a safe working height or in a suitable working position (The Swedish Work Environment Authority, 2019).

#### *Organisational requirements*

The main factor here to consider as a risk for injury is raised as carrying the load longer distances (The Swedish Work Environment Authority, 2019).

### **2.2.2 Time Pressure as an Influencing Factor**

Time pressure is seen as a risk for injuries when manually handling a load, based on the increased tension in the body and some risk for negligence (The Swedish Work Environment Authority, 2020).

## **2.3 Cooling**

The following section explains how different active and passive cooling systems work, along with insulation. It also illuminates two different existing cooling solutions from Dometic.

### **2.3.1 Broad Concepts of Cooling a Space**

This section describes some technical background to cooling a space, as well as introducing some cooling alternatives.

#### **2.3.1.1 Cooling Capacity vs Passive and Active Thermal Energy Loss**

Cooling capacity is seen as a cooling system's ability to remove heat from a space, with watts (W) used as the unit of measurement (Cooling Power, 2018).

The expert interview on cooling systems, see section 4.1.6.3, introduces two parts of thermal energy loss, being either passive or active. Passive thermal energy loss is the energy lost through insulation and seals of the cooled space. Active thermal energy loss is the energy loss through for example opening doors to the cargo space, resulting in cooled air being replaced by warmer air. To ensure a stable cooling system, the cooling capacity needs to cover the sum of the passive and active thermal energy loss from the cooled area.

#### **2.3.1.2 Passive vs Active Cooling**

Different methods can be used in order to cool a space. These methods can be divided into passive and active cooling techniques (Intersam, 2021). Passive cooling

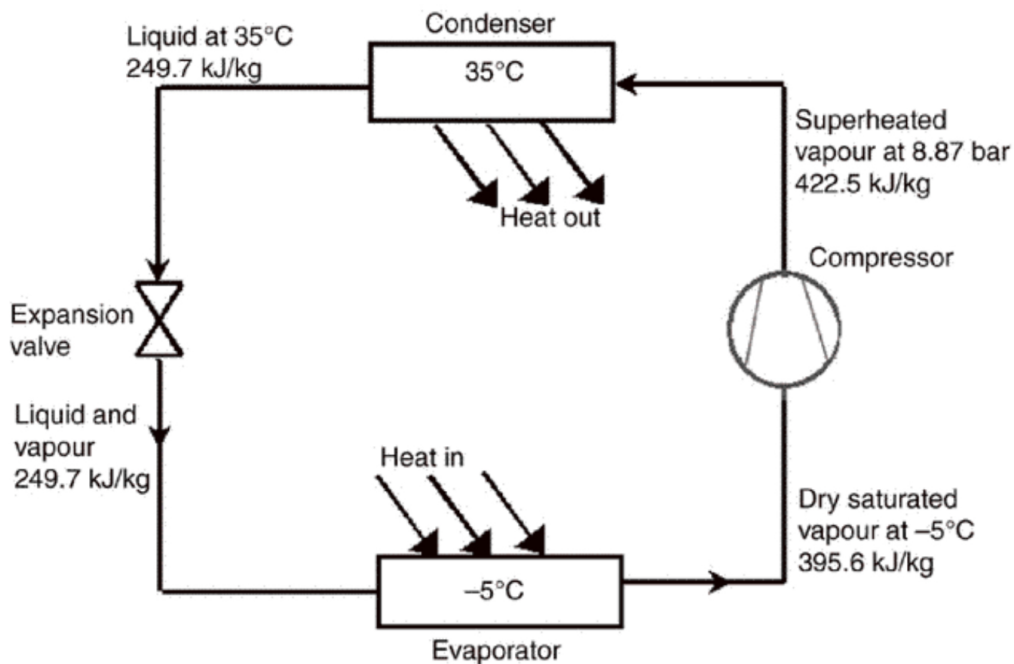
is generally seen as a cooling method without any active elements, see section 2.3.3. Active cooling is when active components are used as part of the cooling system in order to regulate the temperature, see section 2.3.2. The most common is a closed circuit circulating refrigerant with a compressor, condenser and evaporator to remove heat from the air in the space to reach an intended temperature.

## 2.3.2 Active Cooling Systems

Active cooling systems are cooling systems with active components that utilize power to keep them operational. This section describes the active cooling system that was deemed viable in the project, which was vapor compression cooling. Other cooling techniques that were identified but discarded after they had been researched were evaporative cooling, absorption cooling and thermoelectric cooling.

### 2.3.2.1 Vapor Compression Cycle Cooling

The vapor compression cycle is used for refrigeration and works by evaporating and condensing a medium (Hundy et al., 2016, p. 19). It is dependent on four components: a compressor, a condenser, an expansion device and an evaporator (Connor, 2019, p. 21).



**Figure 2.1:** Vapor compression cycle with pressure and enthalpy values for R134a, from Hundy et al. (2016).

A vapor compression system can be seen in Figure 2.1 and it works by circulating a liquid refrigerant such as R134A in the system, to transfer heat away from a cold reservoir. The expansion device creates an obstruction in the flow of the high pressure liquid (R134A), which in turn lowers the liquid's pressure and boiling point

and turns a part of the liquid into vapor. During this phase change, the coolant's temperature drops significantly. This now cold liquid will thereafter be transported to the evaporator, where it will absorb heat from the cold reservoir, i.e., the air in the space that is cooled. This absorbed heat will vaporize the liquid completely. In order to make this process repeatable, the liquid travels to a mechanical compressor which will increase the pressure in the vapor, and consequently its temperature. Thus, the final step before the vapor can return to the expansion device is to turn the vapor back into a liquid, and this is done at the condenser which cools the vapor and turns it into a liquid again. The vapor compression cycle can thereafter be repeated (Hundy et al., 2016).

### 2.3.3 Passive Cooling Systems

Passive cooling systems are cooling systems that do not require an active components, and thus no power supply to function during use (Intersam, 2021). Some examples that could be utilized to either cool a large empty space, or help to freeze a smaller space are phase change materials (PCM) and dry-ice.

#### 2.3.3.1 Passive Phase Change Materials (PCM)

Phase change material (PCM) is a term used in several different industries, described as a substance that through a phase change, i.e. from liquid to solid absorb or release large amounts of latent heat (Paus, n.d.). Consequently, products using PCM release large amounts of energy when changing into a frozen, solid state. These PCM products then absorb the equal amount to this energy when melting and going back to a liquid state (Phase Change Material Products Limited, 2011).

Passive PCM is here used to describe the cooling technique that utilizes blocks of a PCM. The PCM is then contained in a plastic block. To 'charge' the PCM, the blocks need to be put in the freezer and reach a state of being fully frozen before being taken out and used as part of a passive cooling solution. Passive PCM can be used for the creation of both refrigeration and freezer temperatures (Polibox, n.d.; iFoodbag, n.d.).

Additional research of PCM consisted of scanning the web for existing PCM product solutions, to see if it could be a viable solution to cool the entire cargo space of Re:Volt. This use case would have been to add one larger or several smaller passive PCM blocks to an insulated box of expanded polypropylene (EPP) or similar material. The volume of the insulated box varied throughout the investigated product offering. An average box was estimated to be around 50 liters, but larger and smaller alternatives were also available. The boxes also seemed to be top-loaded in general, through a lid that can be fully taken off. The wall thickness of available insulated boxes was estimated to be in the range of 30–60 mm (iFoodbag), n.d.; Polibox, n.d.).

The weight, dimensions and cooling capabilities was found to vary somewhat between products. PCM blocks relevant to consider for refrigeration temperatures were seen as those cooling one insulated box of an average of 50 liters per PCM

block. The weight of the PCM block was generally found to be in the range of 3–6 kg. Dimensions were also found to be similar within this category of PCM blocks, being in the range of 480x280x28 mm to 600x400x28 mm (Polibox, n.d.; iFoodbag, n.d.; Phase Change Material Products Limited, 2011). After the PCM block has gone through its phase-change to liquid it can no longer provide satisfactory cooling and needs to be refrozen before its next use. The freezing time for PCM blocks vary between 6–24 hours, depending on aspects such as for example the refrigeration unit used and the air circulation around the PCM blocks in the freezer. It is recommended that a second set of PCM blocks are used in rotation with the first, so that an already frozen PCM block can be collected directly, instead of requiring a waiting time for the PCM block to freeze in between uses (ScanBox, 2020).

One application of having one larger PCM block in an insulated box of 50 liters or 151 liters claims to meet food temperature requirements for at least 8 hours with an outside temperature of up to 35°C (iFoodbag), n.d.). Another example of a similar product was given by Phase Change Material Products Limited (2011), stating the cooling capacity of one PCM block as 288 Wh. The choice of cooling technique was discussed in the following section, 4.1.7.6.

### **2.3.3.2 Active Eutectic Plates**

Active eutectic plates is a cooling technique where the plates are cooled through a compressor connected to a power supply, but is disconnected and seen as a passive cooling technique when in use. The plate has a pipe running through which is connected to a condensing unit, and the plate itself is it filled with an eutectic solution that freezes at a specific temperature (EUTECTIC (ATCINT), n.d.). This temperature is lower than the freezing temperature of the individual components of the eutectic solution (Salgaonkar, Kulkarni, & Kulkarni, 2016). The freezing temperature of this can vary depending on the needs, and can be used for refrigeration and freezer temperatures. The cold eutectic plate then use its low temperature to maintain a certain temperature of the space where it is installed. Eutectic plates are commonly seen installed in cargo spaces where several plates are used, see Figure 2.2, as well as part of fully furbished delivery vehicles (Cold Car USA, n.d.; Iraq Cooling and Industrial Refrigeration, n.d.).

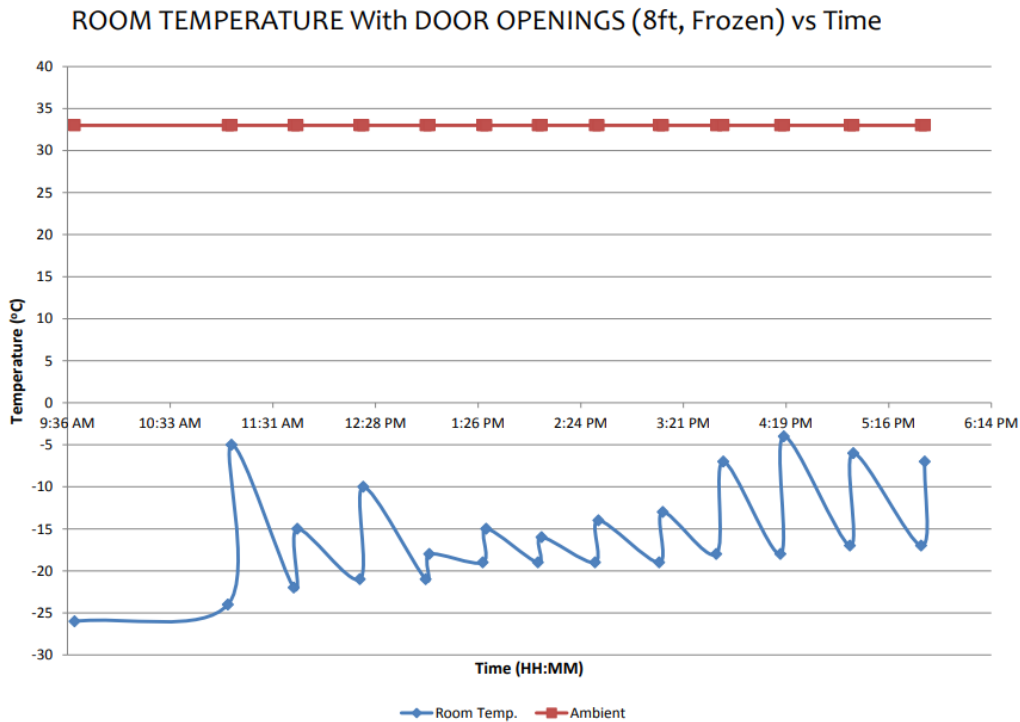


**Figure 2.2:** An example installation of active eutectic plates in a cargo space, from IndiaMART (n.d.).

Publicly available data on the specifications and cooling capacity of active eutectic plates was found to be limited. The direct contact established with companies offering eutectic plate products did not result in any additional information provided.

Eutectic plates are commonly sold as part of a fully furnished delivery vehicle (Cold Car USA, n.d.; Iraq Cooling and Industrial Refrigeration, n.d.). Research was carried out online to investigate specifications of some available solutions of active eutectic plates in order to see their performance when installed in vehicles to cool the cargo space. An effort was made to make contact with several companies offering eutectic plate products but no answers were received, unfortunately.

In order to estimate the time it takes for a cooling system using eutectic plates to reestablish a satisfactory temperature an example made available online was observed, see Figure 2.3. It was only partly seen as representative for the investigated use in Re:Volt. The case being for frozen temperatures and another size of both the size of the cargo space and the size of the cooling element than what would be relevant to implement in Re:Volt. Still, it was seen as a relevant guideline to take into consideration regarding the use of eutectic plates. It can be seen that a door opening has a major impact on the temperature in the cargo space, requiring on average an estimated time of around 30 minutes to reach the intended temperature again.



**Figure 2.3:** An example showing the impact of door openings on the temperature of a cargo space with an installed active eutectic plate as the cooling system, from PLUSS (n.d.).

When referencing three available product sheets for eutectic plates, it was seen that the size and weight of one plate could vary greatly. The range for the surface area (that is exposed towards the center of the cargo space) was identified to be  $0.5\text{ m}^2$  to  $2.7\text{ m}^2$ . Their weight ranged from 25 kg to 88 kg (ATC International, n.d.; PLUSS, n.d.; EUTECTIC (ATCINT), n.d.). It was difficult to estimate a cooling capacity and cooling rate of investigated eutectic plate applications, based on the limited information available. An example of an investigated product was a plate with a surface area of  $0.58\text{ m}^2$  and that weighed 40 kg. It was found to be presented as intended for cooling temperatures of  $2^\circ\text{C}$ – $8^\circ\text{C}$ , being able to keep a temperature in the cargo space below  $4^\circ\text{C}$  for around 11 hours when no door openings were made. The energy extraction rate per plate was then said to be 1710 Wh per plate (PLUSS, n.d.). According to EUTECTIC (ATCINT) (n.d.), it takes 10–12 hours for the eutectic plates to be refrozen between uses. During this time, the eutectic plates stay in the space where they are installed, while being connected to an external compressor unit (EUTECTIC (ATCINT), n.d.).

### 2.3.3.3 Dry-Ice

Dry-ice is the solid form of carbon dioxide ( $\text{CO}_2$ ), and has a temperature of  $-78.5^\circ\text{C}$ . When the surrounding temperature is warmer than this, the dry-ice evaporates to gas form. Dry-ice is to be seen as a type of perishable goods, generally to be used within two days of being received from the supplier (Gases, n.d.).

Dry-ice is a passive cooling solution utilized during the transportation of frozen products, seen as an option to maintain an unbroken cold chain during transportation (Messer, n.d.). The rate of sublimation of dry-ice from solid to gas can vary, for example based on the insulation used. Generally 2–5 kg dry-ice sublimate per 24 hours in transport (UPS, n.d.). How much dry-ice is needed is also dependant on the mass of the cargo to be cooled. If the mass is larger, for example 9 kg, Cardinal Health (2020) states that 2 kg dry-ice is needed for four hours of transport.

Dry-ice is seen as a type of hazardous substance. One area this is seen in is regulations regarding manual handling using safety equipment such as gloves, based on the dry-ice being the low temperature of  $-78.5^{\circ}\text{C}$ . Another area is regarding air ventilation requirements and concentration limits. Dry-ice results in pure  $\text{CO}_2$  gas when phase-changing from solid to gas in warmer temperatures. When mixing with the air this can pose a risk, with  $\text{CO}_2$  being a suffocating gas (Praxair, 2016).

### **2.3.4 Available Active Cooling Systems Offered by Dometic**

Two different active cooling systems that Dometic offered were researched: Frigo DC2500 and ColdMachine. Frigo DC2500 is a complete product and cooling system kit, whereas ColdMachine is a product group where different compressors and evaporator units can be combined to create a cooling system. The feasibility of these cooling systems' power consumption related to the battery capacity of Re:Volt was discussed with the director of electric vehicle technology at Clean Motion.

The two active cooling systems offered by Dometic can be described as Frigo DC2500 generally being used in transportation vehicles and ColdMachine being used in different smaller, site-built applications where some leftover space is used (Dometic Group, 2020).

#### **2.3.4.1 Frigo DC2500**

Dometic Frigo DC2500 is an active cooling system utilizing compressor cooling technology, see section 2.3.2.1. It is an complete cooling kit mainly consisting of one compressor and condenser unit and one evaporator. The compressor and condenser is placed outside of the space to be cooled, generally in an available space in the chassis of the vehicle. The evaporator is to be placed inside the space to be cooled, generally fastened in the roof the closest to the driver cabin 4.1.6.2.

Frigo DC2500 includes additional features such as automatic defrosting and a smaller control panel possible to mount in the driver's cabin to display current temperature in the cooled space or potential service messages. Frigo DC2500 is also approved according to the certification ATP as well as the standard DIN 8958. Two approvals both covering technical requirements, ATP regarding transportation of perishable food and DIN 8958 regarding cooling equipment in insulated spaces used in transportation (Dometic Group, 2021a).

## 2. Theory

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### *Specifications*

Some highlighted specifications of Frigo DC2500, according to Dometic Group (2021a):

- The total weight of the full installation of the cooling kit is 43 kg.
- The dimensions of the evaporator fastened within the cooled space is 660x157x500 mm.
- The cooling capacity to keep a temperature of 0°C in the cooled space when driving in an outside temperature of 30°C is 1030 W.
- The temperature range varies with the refrigerant, and can be both refrigeration and freezer temperatures. Focus is put on using the refrigerant resulting in an optimal cooling temperature of 0°C. The volume Frigo DC2500 has capacity to cool in this case is up to 5 m<sup>3</sup>.
- The air flow volume is 780 m<sup>3</sup>/h.
- The power consumption with a temperature outside of 30°C and the temperature within the cargo space is kept at 0°C is 68 A. See more in the case presented below.

### *Case study Frigo DC2500 power consumption*

A case is provided by the development engineer with cooling technology expertise as a follow up to the second interview conducted, see section 4.1.6.3. This case covered the power consumption of Frigo DC2500 in a case deemed as straining on the cooling system, near extreme outdoor temperatures. The case being to keep the temperature within the cargo space at 0°C when the temperature outside is at 30°C. The number of door openings per hour was set to six and ten openings. This range was deemed representative of the estimated use of Re:Volt for delivery of groceries to an end customer. This range was later confirmed, see section 5.1.1.1. The k-factor, see Figure 2.4 is based in the insulation of the cargo space.

This was seen as an estimate, where all cooled air was exchanged for warm outside air once during one door opening part of one delivery. The model was also made at a stage when the cargo space volume of Re:Volt was estimated to be 2.5 m<sup>3</sup>. The cargo space volume was later estimated to be closer to 2 m<sup>3</sup>, used in further calculations. The cargo space volume estimated as slightly higher in initial calculations does not pose an added risk of underestimating the cooling demand being the sum of passive and active thermal energy loss during use.

Volume m <sup>3</sup>	2,5 m <sup>3</sup>	2,5 m <sup>3</sup>
Door Opening / per hour	6	10
Temperature Cargo space	0°	0°
Outdoor temperature	30°C	30°C
Insulation k Factor	0,4	0,4
Voltage V	12,5 V	12,5 V
Cooling Demand (with switch OFF Time)	655 W	715 W
Power Consumption (at Specific environment / with Switch OFF)	570 W	622 W

**Figure 2.4:** Case Frigo DC2500.

In this case it was found that the combined passive and active thermal energy loss is 655 W with six door openings per hour and 715 W with ten door openings per hour, see Figure 2.4. In order to cover this thermal energy loss with an adequate cooling capacity using Frigo DC2500, the required power consumption of the cooling system was calculated to be 570 W and 622 W respectively.

*Discussion on the power consumption of Frigo DC2500 in relation to the battery capacity of Re:Volt*

The power consumption of Frigo DC2500 in relation to the battery capacity of Re:Volt was discussed with the director of electric vehicle technology at Clean Motion. Concerns were raised around the relatively higher power consumption in use scenarios similar to the case covered. With this reservation, the cooling system was seen as a feasible alternative to further investigate for implementation, with no elimination required based on the power consumption.

*Air flow rate of Frigo DC2500*

As presented in the specification of Frigo DC2500, the air flow rate of the cooling system is 780 m<sup>3</sup>/h when operating at an outside temperature of 30°C and keeping the cargo space temperature at 0°C (Dometic Group, 2021a). From this it was calculated that it would take 9.217 seconds for the Frigo DC2500 cooling system to release 2 m<sup>3</sup> (the internal cargo volume of Re:Volt) of cold air into the refrigerated cargo space.

$$\text{Air flow volume in m}^3/\text{s}: \frac{780\text{m}^3}{\text{h}} = \frac{780\text{m}^3}{3600\text{s}} = \frac{0.217\text{m}^3}{\text{s}}$$

$$\text{Time to fill 2 m}^3: \frac{2\text{m}^3}{0.217\text{m}^3/\text{s}} = 9.217\text{s}$$

However, that would not mean that Re:Volt's cargo space would reach a temperature of 0°C in that amount of time. The actual time that it would take was not determined, but estimated to be a few minutes.

### 2.3.4.2 ColdMachine

Dometic ColdMachine is the collective name of several separate units that are used to build up an active cooling system. Focus was put on one compressor unit called Dometic ColdMachine CU-96, installed together with one evaporator unit. The evaporator unit Dometic ColdMachine VD-14N is used for refrigeration and the evaporator unit VD-16 is used for freezing. All specifications are for a fully insulated space, having an insulation panel thickness of 35 mm. Since ColdMachine is not a finished product it does not include any additional features (Dometic Group, 2021b).

*Dometic ColdMachine CU-96*

Dometic ColdMachine CU-96 is part of the 90 series, seen as the compressor with the largest cooling volume capacity out of the cooling units intended to be used for site-built cooling solutions. This compressor is suitable to use together with both refrigerator evaporators such as VD-14N and freezer evaporators such as VD-16.

With this being the compressor unit part of a cooling system, it is to be placed outside of the cooled space. CU-96 has the dimensions 220x230x177 mm and weigh 6.5 kg (Dometic Group, 2021b).

*Dometic ColdMachine VD-14N (when used with ColdMachine CU-96)*

Dometic ColdMachine VD-14N is an evaporator suitable for refrigeration temperatures. VD-14N has the dimensions 220x275x65 mm, weigh 2.5 kg and has a maximum cooling volume of 300 liters. The power consumption is 80 W (Dometic Group, 2021b).

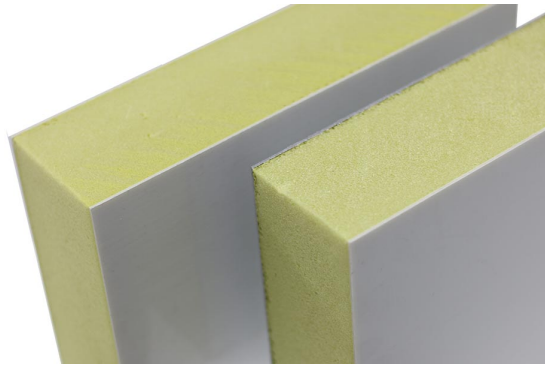
## 2.4 Insulation

Insulation can be seen as the most efficient way to maintain lower temperatures in an enclosed space, acting like a barrier to reduce the transmission of heat energy into the space (Mecalux, 2017). The cooled space has to be insulated from all sides in order to minimize the passive thermal energy loss 4.1.6.2.

The insulation material using sandwich panels with a core of polyurethane (PUL) was identified as standard for various refrigeration and freezer applications, see section 4.1.6.2. This insulation material was also further investigated and confirmed to be seen as standard in the industry (Mecalux, 2017; ISOPA - the European Diisocyanate and Polyol Producers Association, n.d.-a).

### 2.4.1 Insulation Material: Polyurethane

A PUL-panel is a panel of even thickness consisting of Polyurethane foam, see Figure 2.5. This material is seen to offer highly effective insulation for the material thickness needed, also being considered a lightweight insulation material. This is supported by a closed cell structure encapsulating insulating gas within the material (ISOPA - the European Diisocyanate and Polyol Producers Association, n.d.-b). This insulating gas is kept within the material through an outer aluminium layer to the insulation panels 4.1.6.2. This outer layer of the insulating panel should be kept intact to the utmost to maximize the time this gas is kept within the material, increasing the insulation efficiency 4.1.6.3.



**Figure 2.5:** The cross section of two PUL-panels used for insulation, from Topolo (n.d.).

The properties of using PUL-panels for insulating cooled spaces are further detailed as beneficial when it comes to transport, as part of keeping the cold chain intact when transporting groceries (ISOPA - the European Diisocyanate and Polyol Producers Association, n.d.-b).



# 3

## Methods

This chapter describes methods that have been used during the project.

### 3.1 Structured Interview

According to Wilson (2013, p. 6), you require an interviewer, a participant, and optionally a notetaker to perform a structured interview. These types of interviews are often conducted by one person asking the questions with the additional person aiding by taking notes, especially if recording is not allowed. Wilson (2013, p. 2) also states that the pre-determined format in a structured interview is supposed to be followed with as little deviation as possible.

### 3.2 Semi-Structured Interview

Wilson (2013, p. 24) describes that a semi-structured interview consists of both open and closed pre-determined questions, with room to ask follow-up questions. The interview type also have the following format: they start with an introduction and the purpose of the interview, followed by a list of topics that have related questions, continued by probes and prompts, and ends with closing comments. Wilson also states that the goal of such an interview is to be systematic but allow yourself to explore other relevant topics. Consequently, they can be used to gather facts, opinions and attitudes (Wilson, 2013).

### 3.3 Observations

Kawulich (2005) explains that observations can provide data on for example non-verbal expressions and how much time users spend on different activities, arguing for it being a qualitative data collection method. It is believed that the method can increase the validity of a study and shed light on actions and events that participants might be uncomfortable or unwilling to share in interviews, surveys, or other quantitative methods. A limitation with the method is that people might change their behaviour if they know that they are being observed. Kawulich (2005) gives four different ways of conducting an observation, one being called *the observer as participant*. This is stated as the most ethical approach. In this approach, the researcher will not be a member of the group and not partake in any core activities, but will disclose their position as an observer and data collector. A downside is

that the members of the group can control the amount of information given to the researcher (Kawulich, 2005).

It is also noted that the researchers that conduct the observation has to have a sense of objectivity and that they should blend in to the studies environment in a natural way, so the participants can act naturally (Kawulich, 2005). In addition, it is also important to have a non-judgemental attitude and be open to the fact that people make mistakes.

## 3.4 HTA - Hierarchial Task Analysis

A hierarchial task analysis is a process of decomposing tasks into subtasks to a level of detail that is desired by the team (Hollnagel, 2003, p. 18). The aim of an HTA is to identify sources that could cause failure in a task, and thereby propose solutions so such failures. Tasks and subtask are operations specified to achieve goals and subgoals. Hollnagel (2003, p. 18) explains how an HTA is carried out in the following steps:

1. Decide the purpose(s) of the analysis.
2. Get agreement between stakeholders on the definition of task goals and criterion measures.
3. Identify sources of task information and select means of data acquisition.
4. Acquire data and draft decomposition table or diagram.
5. Recheck validity of decomposition with stakeholders.
6. Identify significant operations in light of purpose of analysis.
7. Generate and, if possible, test hypotheses concerning factors affecting learning and performance. (Hollnagel, 2003, p. 18)

## 3.5 REBA - Rapid Entire Body Assessment

A Rapid Entire Body Assessment is a simple pen and paper method that requires minimal equipment (Hignett & McAtamney, 2000). Hignett and McAtamney (2000) explains the aims of REBA in the following list:

- Develop a postural analysis system sensitive to musculoskeletal risks in a variety of tasks.
- Divide the body into segments to be coded individually, with reference to movement planes.
- Provide a scoring system for muscle activity caused by static, dynamic, rapid changing or unstable postures.
- Reflect that coupling is important in the handling of loads but may not always be via the hands.
- Give an action level with an indication of urgency (Hignett & McAtamney, 2000).

Specific body segment codes were developed as part of REBA based on previous ergonomic data collection methods such as NIOSH, Rated Perceived Exertion (RPE), OWAS, RULA (Hignett & McAtamney, 2000). The method is conducted by taking a picture of a position or posture that should be analyzed, to thereafter give scores to different parts of the body by utilizing three tables that can be seen in (Middlesworth, n.d., p. 2). The scores in the different tables will be used to get a REBA score that will represent what kind of change needs to be implemented, depending on if the score equals 1, 2–3, 4–7, 8–10, or 11+. A score of 1 would be negligible and a score of 11+ could mean that the position is of very high risk and change needs to be done immediately (Middlesworth, n.d.).

### **3.6 Affinity Diagram**

An affinity diagram is composed of qualitative data of the users of a product and thereafter grouping it in categories (Thronton, 2020). It is also stated that the data can be gathered through different methods such as: observations, usability testing, and surveys. All of the findings will thereafter be written down on cards (such as a sticky note), so they can be rearranged and organized into categories. The information is then organized into groups, a process called affinity mapping. When finished, statements should be made for each group providing the key insights from the respective group. The finished output is called an affinity diagram (Thronton, 2020).

### **3.7 Personas**

According to Wikberg-Nilsson, Ericson, and Törlind (2015), a persona is a fictive person that can fit a context and that are a part of the target user group. The purpose is to create a living description of the primary users and an understanding of the users in the given environment. The method acts to support empathy with the users and their needs (Wikberg-Nilsson et al., 2015).

### **3.8 Function Tree**

Österlin (2016) describes a function tree as a picture that provides an overview over the functions that define a product. The tree is composed of a hierarchical list of functions that have different abstraction levels. The ones closer to the main function at the top have a high abstraction level, and could answer the question "why?", or in other words, what functions are needed for the product to work. Further down in the tree, the "how?" becomes more clear, and thus resulting a lower abstraction level. Here, there will be easier to find concrete solutions (Österlin, 2016, p. 51).

### 3.9 Weighted Criteria Matrix

Criteria that have been weighted can be used in evaluation matrices in order to understand the viability of different concepts or solutions. Johannesson, Persson, and Pettersson (2013, p. 187) explain that there are no completely objective methods to weigh criteria against each other, even if that is desired in development teams. However, a weighted criteria matrix is one method that aims to weigh criteria against each other in the most objective way possible. Figure 3.1 shows an example of this kind of matrix. The chosen criteria are stacked against each other in the rows and columns. Then, starting from the left to right the criteria in the leftmost column should be deemed one of the following compared to the criteria stacked against it in the columns to the right: *way less important* = 0, *equally as important* = 0.5 or *way more important* = 1. The criteria are not compared against themselves. When the comparisons are done, their scores can be added up row by row, which will show their weight compared to each other. The values can thereafter be normalized to a 1–5 och 1–10 scale, since that can be more desirable than having a 0–1 scale.

Criteria	Offer easy Loading	Ensure product quality	Enable sustainability	Ensure energy efficiency	Offer easy unloading	Support delivery to door	Sum	Sum/Tot
Offer easy Loading		0	1	0	0	1	2	0,13
Ensure Product quality	1		1	1	1	1	5	0,33
Enable sustainability	0	0		0	0	1	1	0,07
Ensure energy efficiency	1	0	1		0,5	1	3,5	0,23
Offer easy unloading	1	0	1	0,5		1	3,5	0,23
Support delivery to door	0	0	0	0	0		0	0,00
						Tot	15	1,00

Figure 3.1: Example of a weighted criteria matrix.

### 3.10 Concept Comparison Matrix

A concept comparison matrix is used to compare and score concepts against each other based on predetermined criteria, that describes attributes that should be obtained in the end product (Wikberg-Nilsson et al., 2015). The importance or weight of each criteria compared to the rest of the criteria can be determined in a weighted criteria matrix, described in section 3.9. A concept comparison matrix is structured by firstly writing all criteria in the leftmost column, followed by a column with each criteria’s respective importance (weight), see can be seen in Figure 3.2 and it. All concepts are thereafter stacked against each other on the following columns to the right. This step is followed by giving the concepts a score from 0–3, where 0 equates to *does not fulfill criteria* and 3 equates to *fulfills criteria well*. The scores are thereafter multiplied with their respective weight, and then added up to get a final score. The winning concept’s weak points can thereafter be analysed for future improvements.

Criteria	Weight	Concept A freezer	Concept B freezer	Concept C freezer
Offer easy Loading	5	1,0	2,0	3,0
Ensure Product quality	10	0,0	1,0	3,0
Ensure energy efficiency	6	2,0	3,0	1,0
Offer easy unloading	7	3,0	2,0	3,0
Enable sustainability	3	1,0	3,0	1,0
Supportive functions	0	1,0	1,0	1,0
Sum (weight * score)		41	61	75

Figure 3.2: Example of a concept comparison matrix.

### 3.11 Double Diamond Design Process

Double diamond is a way to describe and visualise a design process, broken down into four different phases being *discover*, *define*, *develop* and *deliver*, see Figure 3.3 (Ball, 2019). The two phases of defining, e.g., made up of research of user needs and develop, e.g., consisting of the development and testing of several potential solutions, are both described as more diverging phases. The define phase of defining the challenge and making sense of the findings from the discover phase and the deliver phase where a single solution is chosen and validated are both seen as more converging phases (Ball, 2019).

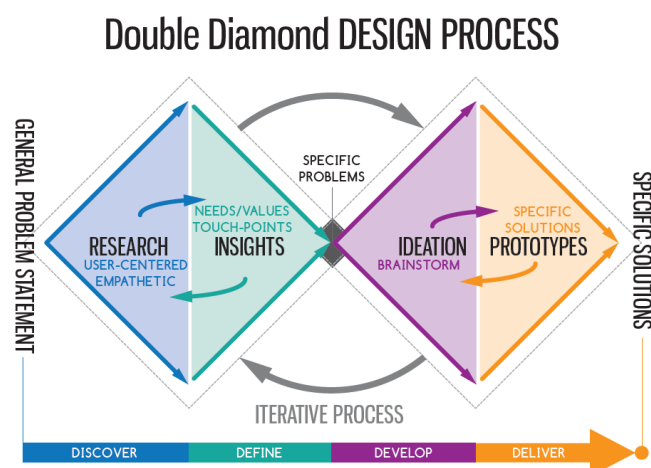


Figure 3.3: Visualisation of a double diamond design process, from Prd (n.d.)



# 4

## Procedures and Results: First Iteration

This chapter describes how the first iteration of the project has been carried out. It consists of Research Phase 1, Ideation Phase 1 and Evaluation Phase 1. The end of the evaluation phase acts as a starting point to the second iteration. The process could be compared to the double diamond method, see section 3.11, where each iteration corresponds to a diverging and converging round.

### 4.1 Research Phase 1

Areas that were researched in this first phase of the project are: rules and regulations related to the food industry, the market segment, the users, the potential customers as well as current cooling solutions. The goal of this phase was to identify the needs of customers of the Re:Volt vehicle, the needs of users interacting with Re:Volt as well as identifying standardized cooling solutions and insulation materials that are being used in current cooling solutions on the market.

#### 4.1.1 Rules and Regulations related to Temperature for Transport in the Food Industry

**Procedure:** A literature study was made, see section 2.1, of the most updated Swedish food sector guidelines being published by Swedish Food Retailers Federation (2021).

A direct contact was made with those responsible for managing the Swedish food sector guidelines published by the Swedish Food Retailers Federation, part of the Council for Cold-and Frozen Chain (Rådet för kyl-och fryskedjan). The reason for this was seeking clarification regarding rules and regulations for smaller cargo vehicles more close to Re:Volt in size as well as related to the timescale of transportation.

**Results:** The results of the literature study covering up to date official guidelines for the Swedish food sector can be seen in section 2.1.

Through contact with those responsible for managing the Swedish food sector guidelines it was found that the legislation and regulations for vehicles that are smaller

than light duty trucks are lacking regarding transport of cold goods, including covering newer variants of transportation alternatives related to last mile delivery of food. It was decided to follow rules and regulations fully covered by the documentation from the Swedish Food Retailers Federation, thus following the same rules and regulations regarding cold transport of food as that using heavy and light duty trucks. (Swedish Food Retailers Federation, 2021).

### 4.1.2 Rules and Regulations Related to Work Environment

**Procedure:** A literature study was made, see section 2.2, of the most updated Swedish work environment law and regulation. Mainly published by The Swedish Work Environment Authority (2020).

**Results:** The results of the literature study of current Swedish work environment law and regulation regarding manual labour can be seen in section 2.2. A selection of different factors were seen as the most relevant to consider as risks that could result in injuries related to manual handling, mainly related to the physical ergonomics for prevention of musculoskeletal disorders.

### 4.1.3 Understanding the Market Segment of Vehicles for last mile delivery of groceries

In order to better understand the delivery industry, the delivery vehicles and corresponding use cases were investigated. The focus was put on the market segment of those offering insulation or active cooling as part of transporting food products. This covered the categorisation of some differently sized delivery vehicle alternatives within the market segment as well as different types of operations. These operations were divided into *quick commerce* and *planned deliveries*, covering for example the differences in delivery radius, time per delivery round and type of delivery.

#### 4.1.3.1 Market Analysis of Current Delivery Vehicles of Different Sizes

**Procedure:** A market analysis was performed based around the size of available cargo space, with a focus on different types of food delivery. The main aim was to gain a better understanding of the range of vehicles operating within the market and what use case was found to be the most common for the different sizes.

**Results:** The vehicle size was generally found to be relative to its cargo space. A categorisation was made of five different cargo space sizes: extra small (XS), small (S), medium (M), large (L) and extra large (XL), see Figure 4.1. An insight was gained regarding the size of Re:Volt compared to other delivery vehicles within the market segment of offering insulation or active cooling as part of transporting food products. This insight being that the size of Re:Volt was placed in between two categories, being the vehicle sizes small and medium.



**Figure 4.1:** Transport alternatives for cooled groceries, with the cargo space ranging from extra small to extra large.

#### *Extra small*

The delivery alternatives here classified as having an extra small cargo space, see Figure 4.1, can be seen as limited to one or only a few deliveries per full load of the cargo space. The cargo space may be actively cooled or heated, but is generally just consisting of an insulated space. Sometimes the cargo space is mounted to some vehicle, sometimes it is carried in the form of a backpack. The cargo space ranges between  $0.06 \text{ m}^3$  and  $0.09 \text{ m}^3$  (Dometic Group, n.d.-b; Guangzhou Acoolda Bags Industry Co.,Ltd, n.d.).

Some example vehicle options for this extra small cargo space size can be seen as EU-mopeds, electric scooters and bikes. This part of the market is generally seen as more suitable for delivery of a shorter distance, often in a more urban area.

#### *Small*

Delivery alternatives classified as having a small cargo space, see Figure 4.1, are suitable for a smaller number of deliveries. The cargo space is mounted onto the vehicle, but might be detachable or stackable in pairs onto the vehicle. All parts of the cargo space are easily accessible from one door. The cargo space is generally not actively cooled or heated (Renault, n.d.; Velove Bikes, n.d.).

Some example vehicle options for this small cargo space size are containerised cargo bikes as well as smaller motorized vehicles with a top speed of 50 km/h, alternatively 30 km/h (Transportstyrelsen, 2020). Similarly to the delivery alternatives for extra small cargo spaces, this part of the market is generally more suitable for delivery of a shorter distance, often in a more urban area. The cargo space ranges between  $0.18 \text{ m}^3$  offering a max cargo weight of 75 kg to a cargo space of  $1 \times 1 \text{ m}^3$  and a max of 2x100 kg cargo weight (Renault, n.d.; Velove Bikes, n.d.).

#### *Medium*

The delivery alternatives classified as having a medium sized cargo space, see Figure 4.1, are suitable for deliveries of up to a few hours, still active in the urban environment but covering larger areas than the vehicles classified as having a small and

extra small cargo space. The cargo space is permanently mounted on the vehicle and can come with active cooling or heating, alternatively being insulated or just offering an enclosed space.

The medium sized cargo space often has several doors and openings to access the cargo space from several directions. Some example vehicle options offering this cargo space size are heavy quadricycles with an added compartment as well as well as smaller light duty trucks. The available cargo weight for vehicles part of this medium cargo space size class is estimated to range from 700 kg to 900 kg. The volume of the cargo space ranges from 2.2 m<sup>3</sup> to 6 m<sup>3</sup> (Inzile, n.d.; Garia Utility, n.d.; E-tron, n.d.).

### *Large*

The delivery alternatives classified as having a large cargo space, see Figure 4.1, are currently the most commonly used for home delivery of groceries. The cargo space of this classification usually has active cooling as well as additional active heating at times. The cargo space is permanently part of the vehicle. It is possible to enter the cargo space and it generally has several doors and openings to access and enter the space.

Vehicles with a large cargo size are suitable for longer delivery times, of several hours, with a relatively large number of deliveries per round. Some example vehicle options offering this cargo space size are light duty refrigerated trucks of up to 3.5 tonnes total weight with a cargo space volume of 18 m<sup>3</sup> and cargo weight of 850 kg and refrigerated vans of 11 m<sup>3</sup> cargo space with cargo weight of 900 kg possible (Transportstyrelsen, 2021; OKQ8, n.d.).

### *Extra large*

This delivery alternative with a cargo size classified as extra large, see Figure 4.1, is commonly used to transport cargo over longer distances, between different stages of the transportation chain of goods but seldom to the end customer. The cargo space generally has a volume of 48 m<sup>3</sup>, with the total weight being above 3.5 tonnes (Delego, 2019). Some example vehicle options offering this cargo space size are heavy duty refrigerated trucks (Coop, 2019).

### *Re:Volt*

Clean Motion's vehicle Re:Volt is seen to be between the size classes small and medium, with a cargo space of 2.5 m<sup>3</sup> and an estimated max cargo weight of around 350 kg (Clean Motion, n.d.-b).

#### 4.1.3.2 Project Brief and Initial Group Discussion at Dometic

**Procedure:** Together with parts of a design team working with the development of cooling products, a cooling technical expert as well as a head of business development for the area of mobile deliveries, a project brief was presented with general discussions where the aim was to get input from a group of people well experienced in working within this area of mobile cooling solutions.

**Results:** The result of this group discussion was a re-evaluation of the customer in focus, also resulting in another analysis of Re:Volt’s market segment and use case when offering a cooled part of the cargo space, see section 4.1.3.3. Insight was also gained into the market trends related to mobile deliveries, mainly discussing the implementation of micro distribution centers in urban areas.

#### 4.1.3.3 Re:Volt’s Market Segment and Use Case

**Procedure:** Research online of different delivery companies was conducted to identify the different types of vehicles they are using, how long they aim to take to deliver their goods, along with how many orders they can handle at the same time.

**Results:** The research resulted in a map (see Figure 4.2) that shows where Re:Volt could be positioned in relation to its competitors.



**Figure 4.2:** A map that shows different companies’ delivery times, order capacity, utilized vehicles, and estimated delivery radii.

Figure 4.2 also illustrates that a part of Re:Volt’s value proposition or a likely area of use could be how its size enables it to compete between and be used in both of the two markets: *quick commerce* and *planned delivery*, leaning slightly more towards quick commerce. Quick commerce or Q-commerce is quick on-demand delivery driven by an E-commerce business model, where the order tends to be delivered within an hour of the order being placed (Pahwa, 2022). Due to such short delivery times, quick commerce has a low carrying capacity of orders, estimated to range from about 1–3 per deliver round. Planned deliveries on the other hand, has in this project been defined as having delivery times exceeding one hour, generally seen to include 10+ orders that are scheduled to be delivered with the same vehicle on a pre-determined route.

The mapped marked segment and use case of different companies operating within the last mile delivery of food products took several aspects into consideration, such as the type of delivery vehicles, estimated delivery radius and time between placing an order and receiving it. An insight gained from this map was that a potential use case of Re:Volt was to combine the operations of planned delivery and quick commerce. Delivering orders placed with a delivery radius and delivery time more close to those of quick commerce while doing a delivery round of planned deliveries in order to better utilize the slightly larger cargo space of Re:Volt compared to those generally used in quick commerce operations. Alternatively, offering an alternative to fill the gap identified between the typical quick commerce operation and the typical planned delivery operation related to the estimated order capacity per delivery round, see Figure 4.2.

### 4.1.4 Understanding the Market Segment of Companies Operating Within Last Mile Delivery of Groceries

Contact was made with companies that were seen as generally known players in the industry of E-commerce within food retail. Those interviewed have been people holding roles with responsibility for transport logistics of home deliveries of groceries.

#### 4.1.4.1 Interview with Transport Manager for E-commerce Logistics Groceries

**Procedure:** A semi-structured interview conducted using an online video conferencing tool with a Transport Manager for E-commerce logistics of groceries. The interviewee was deemed relevant based on their role including logistics responsibility for E-commerce at a large, for a well known brand in the food retail industry. The interviewee wished to not be further disclosed. The aim of the interview was to gain an understanding of the industry of transport of groceries to be delivered to an end customer, seen as part of the area of planned deliveries.

**Results:** The interviewee gave valuable insights regarding the capacity of a delivery vehicle's cargo space, how they loaded and delivered goods, the unloading of goods, along with temperature requirements and cleaning of cargo spaces. These answers were later compiled in the affinity diagram that can be seen in section 4.1.7.1 and more elaborate answers from the interviewee can be viewed in Appendix A, section A.1.

#### 4.1.4.2 Interview with Transport Manager for E-commerce Logistics Groceries Dagab Inköp & Logistik AB

**Procedure:** A semi-structured interview conducted using an online video conferencing tool with a transport manager for E-commerce logistics of groceries for Dagab Inköp & Logistik. The interviewee has long experience of being responsible for logistics within the industry of distributing groceries to stores and E-commerce customers. The aim of this interview was to gain an understanding of the industry of transport of groceries to be delivered to an end customer, seen as part of the area

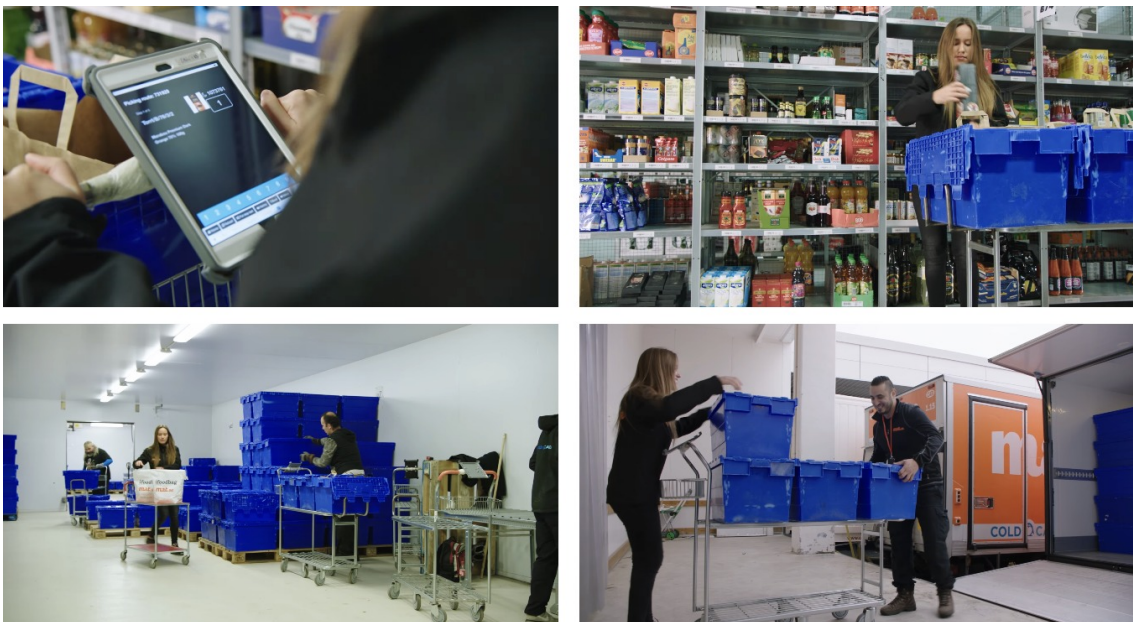
of planned deliveries.

**Results:** The interviewee explain areas such as: An example standard order, their vehicle temperature zones, loading and unloading of goods, their ways of structuring goods, the courier working environment, and their needs regarding the size of a delivery vehicle. These answers were later compiled in the affinity diagram that can be seen in section 4.1.7.1 and more elaborate answers from the interviewee can be viewed in Appendix A, section A.2.

#### 4.1.4.3 Five Online Video Observations of Food Delivery Processes

**Procedure:** YouTube was used to find videos uploaded by food delivery companies, where they showed parts of their delivery processes. Different points of these videos where thereafter screenshotted and key observations were written down on digital post-it notes on the website Miro.

**Results:** Five videos were analysed in total. The videos were from Coop in 2012, Mat.se in 2015, Mat.se in 2018, Mathem in 2016, Mathem in 2020. For a selection of the screenshots from one of the videos were said observations were made, see Figure 4.3. These observations were used to further understand the processes that take place when groceries are being transported from a warehouse or store to an end customer. The findings consequently improved the user journey that is described in 4.1.5.2 and contributed to the the affinity diagram that can be seen in section 4.1.7.1.



**Figure 4.3:** A selection of screenshots from a video uploaded to YouTube in 2015 by Mat.se.

### 4.1.4.4 Direct Contact with Business Managers at Clean Motion for Insights of Potential Customers' Needs

**Procedure:** Several conversations were carried out with business managers at Clean motion, with the aim to take part of their insights of general needs identified in the market from potential customers.

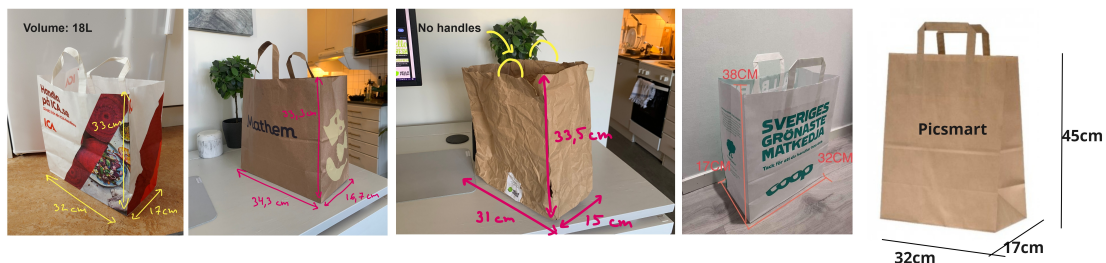
**Results:** The Business Managers' views of the market for Re:Volt, based on the response from potential customers, was that the interest was larger from the quick commerce segment. Re:Volt was seen as a better fit for that type of operation, mainly based on number of orders, order size and location of the delivery also affecting the distance traveled.

It has been seen that the method to handle a larger number of orders during the loading stage of goods varies greatly between different potential customers. Some examples given were the usage of half pallets, rollable shelf units as well as static shelf units with plastic boxes inside the cargo space. Another variation discussed was the way goods were packaged. Some identified potential customers were currently using cardboard boxes of different sizes as part of their transport of goods, but the majority was found to be using paper bags. These insights were utilized in the affinity diagram that can be seen in section 4.15.

### 4.1.4.5 Current Packaging of Groceries

**Procedure:** The range of the size of paper bags used as part of grocery deliveries to an end customer has been identified through video studies as well as direct observations. A selection of these have been measured and compared.

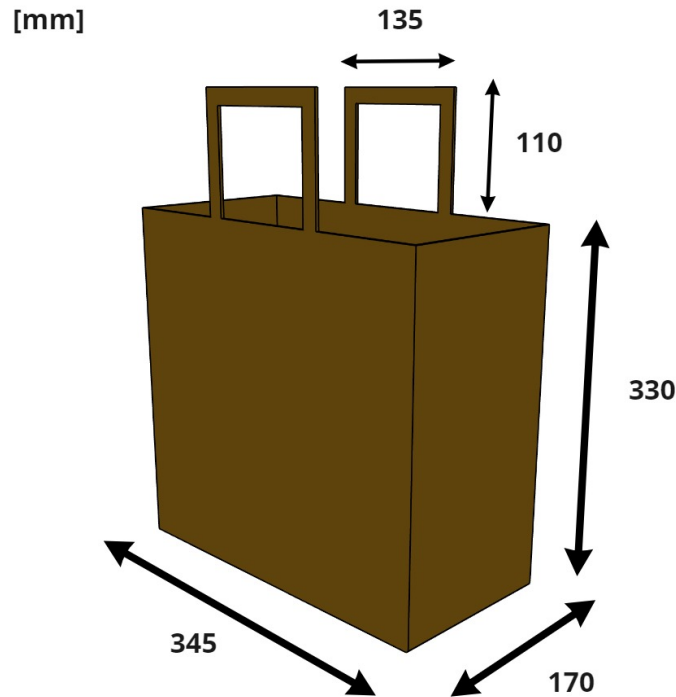
**Results:** Five different sized paper bags were identified as being used within home-delivery of groceries, where the main variation was seen to be the height of the bag, see Figure 4.4. A majority of the bags used where of a lower height. This resulted in a standard paper bag size of 34x17x33 cm to be used in the project moving forward (see Figure 4.5), corresponding to the largest paper bag of those with a lower height.



**Figure 4.4:** Observed paper bag sizes, from left to right being: ICA.se, Mathem, Hellofresh, Coop, Picsmart.

This standard paper bag was based on what has been found to be the most com-

mon packaging method. Still, it has been identified as relevant to still take other variations of packaging alternatives, such as cardboard boxes and taller paper bags into account in creating a solution that can be suitable for a variety of operations and customers.



**Figure 4.5:** Dimensions of a bag that was used in CAD software during concept creation.

### 4.1.5 User Studies

This phase aims to understand each stakeholder that interacts with the product, with a focus on the interaction with the cargo space. The user is seen as those directly or indirectly interacting with the cargo space, see tasks covered in 4.1.5.7. The customer is seen as the organization responsible for the operation offering home delivery of groceries.

#### 4.1.5.1 Target User Group

**Procedure:** The target user group has been identified and demarcated both as a foundation and as a result of the user studies performed.

Initially, the aim for the user studies was to cover both users working with home delivery of groceries as well as users working with more general deliveries. After a first interview with a delivery driver at Bzzt being considered a users working with deliveries not limited to food, see 4.1.5.3, this was re-evaluated. The following user

studies were then limited to investigate home deliveries of groceries.

**Results:** The target user group was seen as quite heterogeneous. When looking at the composed HTA, see section 4.1.5.7 and user journeys, see section 4.1.5.2, the focus was mainly put on the courier of the home delivery of food. This user was generally responsible for the driving of the vehicle as well as the unloading and delivery of goods. Another user part of our targeted user group was those responsible for the loading of goods into the cargo space. Users such as those responsible for cleaning are taken into consideration but not directly seen as part of the target user group.

### 4.1.5.2 User Journeys

**Procedure:** To get a better understanding of how one or several users could experience their interaction with the delivery vehicle throughout the delivery process of groceries to an end customer, a user journey was created.

**Results:** User journey is the term here used to describe and get a brief overview of the interactions users have with the goods and vehicle throughout the targeted part of the delivery process. This targeted part of the delivery process was seen to cover a majority of the delivery process from store or warehouse to the end-customer. It considered all of the interactions from packing groceries into bags in the store or warehouse, to loading the vehicle, and lastly unloading the groceries of the vehicle. The focus was on the parts where Re:Volt as the transportation vehicle would be involved. The intention was that the solution would have a positive influence on this user journey by simplifying- or eliminating steps, along with improving physical and cognitive ergonomics, which in turn could save time, money and improve the health of the staff.

### 4.1.5.3 Interview with Delivery Driver at Bzzt

**Procedure:** A semi-structured interview conducted using an online video conferencing tool. The interviewee has many years of experience working as a courier within quick commerce of general goods delivery. The interviewee had used several smaller, electric delivery vehicles such as for example Clean Motion's vehicle Zbee as well as Renault Twizy. The aim of this interview was to gain an understanding of the user perspective of being the courier delivering goods, in this case being part of quick commerce, using vehicles close in size to Re:Volt's.

**Results:** The interview covered the intended aim, with an added area on insight into the use of the first and only vehicle in use from Clean Motion called Zbee, see Figure 4.6. The interview gave relevant insights to the project regarding the handling of a three wheeled vehicle along with how cargo got handled in smaller vehicles. These answers were later compiled in the affinity diagram that can be seen in section 4.1.7.1 and more elaborate answers from the interviewee can be viewed in Appendix A, section A.3.



**Figure 4.6:** Clean motions first smaller, electric delivery vehicle called Zbee, from Motorzest (2016)

#### 4.1.5.4 Direct Observation of an ICA Delivery Truck

**Procedure:** A large food delivery order (amounting to about 850 SEK) was placed to ICA supermarket. The order contained various different items that required everything from room- to frozen temperatures. At delivery, an observation and quick interview was conducted with one of ICA's delivery drivers.

**Results:** The observation (see Figure 4.7) and the quick interview gave insights around the driver's situation during a delivery as well as the physical structure of the cargo space holding goods in the form of groceries packed in paper bags.



**Figure 4.7:** Photos taken of ICA's delivery truck and cooling boxes, along with their hand computer application and packed grocery bags.

The structure of goods was showcased by the driver, with half the space being re-

refrigerated and half the space being warmer. The goods were secured in colour coded boxes. Red boxes being used in the warmer space and for refrigerated goods in the colder space. Blue boxes, with dry-ice placed in the lid, was used for frozen products in the refrigerated space.

The driver highlighted that heavy lifting would occur and that many delivery drivers had complained about that. He believed that it is was not optimal that the hiring department hired people that were not set out to lift heavy.

The driver was showing how the correct order was identified with a handheld computer attached to the wrist. The boxes where scanned according to what the delivery system showed, and got instant confirmation if it was the correct paper bag part of the current order or not. The delivery system was said to be controlled and planned by an AI.

The driver said that all the orders were reasonably accessible without the need to walk around that much in the cargo area. With the issue that the delivery driver (estimated to be 190 cm tall) thought that the cargo space was very tight. Another issue raised was that the delivery of goods could be stressful at times.

### 4.1.5.5 Three Direct Observations of a Mathem Delivery Truck

**Procedure:** Three different observations were made of Mathem delivery trucks. The first one was an observation of a courier doing his work, being of the cold approach type. The courier agreed to be filmed while he was retrieving an order and was willing to answer some quick questions. The second observation was done of another Mathem truck during an evening delivery. The third observation was made during the delivery of a large food delivery order (amounting to about 1000 SEK) placed to Mathem.

**Results:** The different observations gave a broad insight into the last stage of the delivery process of Mathem. Including for example the structure of goods in the cargo space, the use of additional tools by the driver and the packing methods used.

#### *First observation of Mathem home delivery*

The full cargo space was seen to be cooled by an active cooling unit. Stacked black plastic boxes that held the orders was used in the cargo space. The courier used a handheld computer that resembled a smartphone to scan the orders and the cargo space had plastic curtains to hinder cold air from escaping. The man also clarified that orders from different customers always are held in separate boxes, and that the couriers did not load the orders into the vehicle, they only delivered them. During the delivery, the courier was required to hold two full paper bags and a full plastic bag with frozen products in one hand while stepping down from inside the cargo space and closing the door, see Figure 4.8. When stepping out of the cargo space, the courier was required to exit through a plastic strips curtain covering the opening.

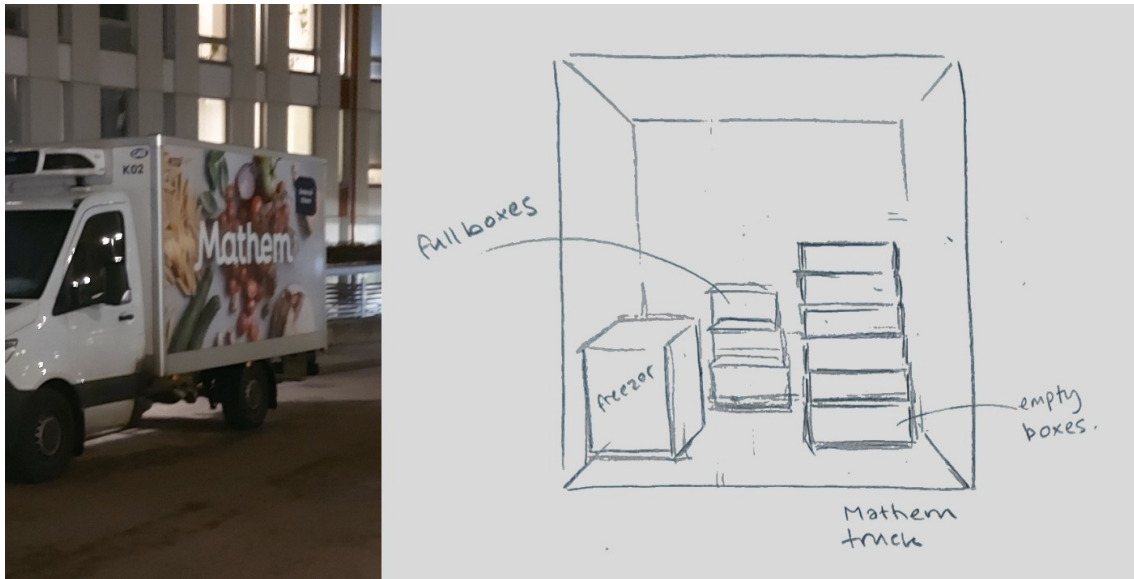
A separate top-loaded freezer box was used in the cargo space, strapped in place. It was observed how the delivering driver was forced into an extreme position bending down into the freezer to retrieve the plastic bag part of the current order.



**Figure 4.8:** Photos from a Mathem delivery, which shows a non-ergonomic position along with three bags being carried by the courier.

### *Second observation of Mathem home delivery*

The second observation (Figure 4.9) showed that not all Mathem trucks have the plastic strips curtain to retain the cold air. The delivered orders resulted in empty boxes that were stacked to the right side of the cargo area. It was observed how the lift of adding newly emptied plastic boxes to the top of this stack resulted in the shoulder being placed in a position where the hand was above the head of the courier. The courier was observed holding three bags in one hand while exiting the vehicle and closing the door. When the delivery driver closed the vehicle the cooling unit made a lot of noise.



**Figure 4.9:** Photo of a Mathem truck (left) with a sketch of what the observed cargo space looked like (right).

#### *Third observation of Mathem home delivery*

An order of groceries amounting to around 1000 SEK was carried out to Mathem. The order resulted in seven paper bags of colonial and refrigerated goods and one plastic bag for frozen goods. The courier said that he had been working for Mathem for three years and that it is important not to twist the body during a heavy lift. The courier was highly aware of ergonomic issues and had some sort of wraps around his wrists and used a metal hook (see Figure 4.10) to pull plastic boxes to himself when he was unloading the truck. The truck had a plastic strips curtain at the opening to retain its cold, and the courier used a two-wheeled hand truck to transport the groceries in three large plastic boxes. Bananas and bell peppers were protected from some of the cold by being placed in an additional paper bag.

# Mathem

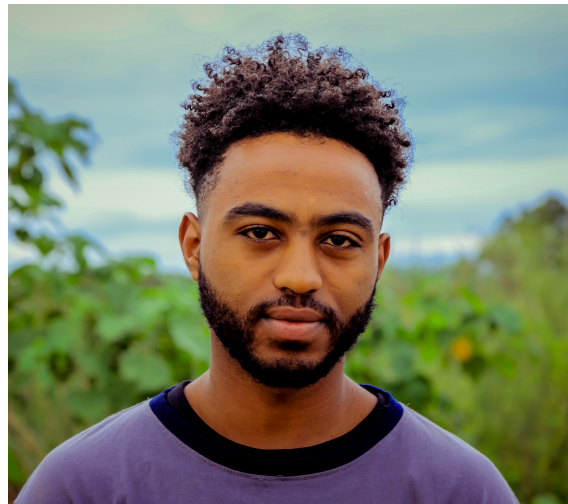


**Figure 4.10:** Photos of how Mathem distributed different types of food in different bags, along with an illustration of a tool that was being used to pull plastic boxes inside of the truck.

## 4.1.5.6 Personas

**Procedure:** Three personas has been formed following the method described in section 3.7, to represent different users within the target user group. These are based on the conducted user studies, mainly through interviews and observations and will be used in later evaluation phases.

**Results:** The personas were formulated to cover the differences within the target user group for height, age, gender, nationality, working situation as well as some insight into personality traits, mainly the approach to handle tasks.



**Figure 4.11:** Persona 1.

### **Persona 1: Erik**

Erik, (see Figure 4.11), is a 21 years old German man. He is 190 cm tall and study electrical engineering. He works part-time at a larger food retailer with home delivery of groceries. Sometimes Erik also helps with the loading of orders into the vehicle.

In his spare time Erik likes to workout and see the heavy lifts part of the work as an added bonus. As a person, Erik likes to follow rules and routines.



**Figure 4.12:** Persona 2.

### **Persona 2: Kim**

Kim, (see Figure 4.12), is 33 years old. They are Spanish, 173 cm tall and works part time as a courier of groceries for a larger food retailer with planned routes and part time as a courier of groceries through quick commerce.

They mostly enjoy the driving aspect of their job, but is getting more and more frustrated with the working conditions, always being in a hurry. Kim also likes to find and use shortcuts wherever it is possible. In their spare-time, Kim likes to dream about the next vacation and watch curling.



**Figure 4.13:** Persona 3.

### **Persona 3: Cecilia**

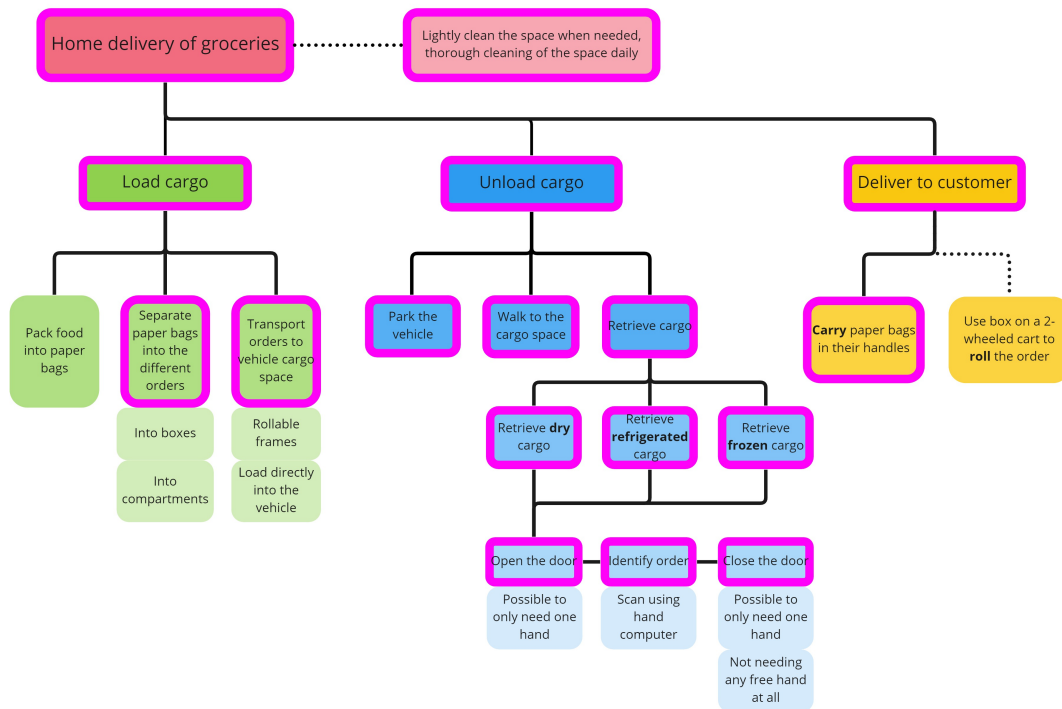
Cecilia, (see Figure 4.13), is a Swedish woman 52 years of age. She is 156 cm tall and has been working full-time as a courier for home delivery of groceries for about 4 years, at a company providing same day delivery. At first she was meticulous with meeting the time requirements part of her everyday work, but now a few years in she prioritises being able to do all manual handling in a safe way.

Cecilia likes to garden and is quite active, but struggles with some back pain. She likes to enjoy life and wants an entry level job to provide for herself.

#### **4.1.5.7 HTA (Hierarchial Task Analysis)**

**Procedure:** A HTA was performed in accordance to method 3.4, with the adjusted aim to understand the basic task structure of users interacting with the cargo space of a transport vehicle used for home delivery of groceries.

**Results:** The resulting HTA in Figure 4.14, where the pink outlines represented the main focus in this project, that also has been described in the user-journey in section 4.1.5.2. The HTA gave an overview of how home deliveries of groceries are conducted. It was later used to define the functions that the final solution was intended to offer.



**Figure 4.14:** HTA of users interacting with the cargo space, performing the main task of home delivery of groceries.

## 4.1.6 Cooling technology

During the initial phase of the project, research was being made around multiple different cooling techniques, such as: absorption cooling, compressor cooling, evaporative cooling, and thermoelectric cooling. Through a dialogue with a cooling technician and expert at a large cooling company insights were gained around feasible active cooling techniques for cooling the cargo space in Re:Volt to temperatures of 2–4°C. The expert suggested compressor cooling for this application when using an active cooling system.

### 4.1.6.1 Factors in Cold Air Escaping From a Refrigerated Space

**Procedure:** The area of what makes cold air escape from a refrigerated space was identified as relevant to investigate further, related to the active thermal energy loss when a door to the cargo space is opened as part of unloading an order from the cargo space. Specifically, insights were sought regarding three different areas related to this. One being if cold air would flow out of the bottom of an open refrigerated space, since cold air is more dense and thus heavier than warm air. The second being if the opening of a door to a cooled space would create a negative pressure at the time of opening, which in turn would pull out the cold air. The third was if the size of the door and duration of keeping the door open impact the loss of cold air. Two people with knowledge on this area were contacted. The first person was an assistant professor at the Department of Energy and Environment at Chalmers

that teaches a course in thermodynamics, and the second was a fifth year student at Chalmers who had taken three courses in thermodynamics and fluid mechanics.

**Results:** The assistant professor said that he believed that it was more of a fluid mechanical problem rather than a thermodynamic one, and that the second and third areas identified would be the main causes of losing cold air, all three areas said to cover valid causes of cold air loss. The fifth year student mentioned that the opening of a door would have to be present in a potential simulation of the problem, because the cold air would otherwise be stagnant. He believed that the turbulence caused by opening a door would be the main cause of cold air loss. An additional point mentioned was that wind passing by the vehicle would cause the cold air inside of the vehicle to mix with the warm air outside of it. It was stated that the cold and warm air would have to mix via convection if no air flow was present, which would be a slow process since it is driven by the change of density in the cold and hot air. Thus, a key takeaway is that an aim should be to minimize the amount of air that can flow out of the vehicle when opening doors.

### 4.1.6.2 First Expert Interview with Development Engineer with Cooling Technology Expertise at Dometic

**Procedure:** A semi-structured interview was conducted using an online video conferencing tool. The aim for this interview was to gain a basic but broad understanding of the area of cooling applications, on a technical level as well as some best practices.

**Results:** The insights gained from the interviewee was from the perspective of someone with thorough experience of acting as the cooling technology expert in a design team. This covered basic knowledge of different cooling techniques, insulation and other variables relevant to the cooling of the cargo space to take into account such as air circulation and doors. These insights were gathered in the affinity diagram that can be seen in 4.15 and contributed to the choice of a cooling technique in section 4.1.7.6. Elaborate answers from the interviewee can be read in Appendix A, section A.4.

### 4.1.6.3 Second Expert Interview with Development Engineer with Cooling Technology Expertise at Dometic

**Procedure:** The interview can be seen as planned and carried out as a semi-structured interview, conducted in person during a visit to Dometic's office in Stockholm. The aim of this interview was to gain a further understanding of how a cooling solution could be implemented in the cargo space of Re:Volt.

**Results:** The aim of this interview can be seen as fulfilled, mainly through insights gained into available alternatives for active refrigeration units, details around insulation choices as well as information useful as a basis for comparison around cooling capacity. These insights were gathered in the affinity diagram that can be seen in 4.15 and contributed to the choice of a cooling technique in section 4.1.7.6.

Elaborate answers from the interviewee can be read in Appendix A, section A.5.

### 4.1.6.4 Group Discussion with Development Engineer and Two Business Managers

**Procedure:** A group discussion with two Business Managers for the Business Area of Mobile Deliveries as well as the previously interviewed development engineer with cooling technology expertise. The aim was to take part of their general insight into the market segment of mobile deliveries and customers active within the area of home delivery of cooled products as well as general thoughts around available cooling systems.

**Results:** The discussions resulted in some insights from this business area of Dometic around the implementation of an active cooling system as well as some of their insights from working with customers in the industry of delivering groceries.

It was shared that contacts to the Business Managers in the industry of home delivery of groceries considers the order size to be quite stable being 6 paper bags, with a standard deviation of 2 bags. One larger retailer of food said that the average volume of frozen products per order is around 5–6 L.

The preferred choice of cooling unit to implement in the final solution according to the Global Head of Business Development of Mobile Delivery was Frigo DC2500. This product being an off-the-shelf product that requires less adaptation to be suitable in the cargo space. It was also seen as more refined than installing a cooling system consisting of for example a separate compressor unit and an evaporator unit, as well as having added features such as temperature control and monitor related interfaces.

An alternative solution to adding a second cooling system for creating temperatures around  $-22^{\circ}\text{C}$  for offering a freezer space was introduced by the business manager as enabling the use of a freezer box called CFX cooler. There were versions already available for floor- or wall mounting.

### 4.1.7 Key Results from Research Phase 1

Findings of this first research phase were summarized in order to support the following phases and iterations in the project development process.

A general takeaway was that the needs of different kinds of customers varied along with the use case where Re:Volt would be implemented. This resulted in an aim towards an adjustable and flexible solution for the continued work forward regarding the loading and unloading process, delivery type and need for a freezer space. The cooling unit for the refrigerated area of the cargo space was decided to be Dometic Frigo DC2500.

### 4.1.7.1 Affinity Diagram

**Procedure:** Data that had been gathered from interviews, observations, and online research were composed in an affinity diagram, by utilizing the affinity diagram method described in section 3.6. An adjustment made to the method was to not only include insights from potential users of the final product, but to also include insights gathered from additional stakeholders in the project such as potential customers and cooling technicians.

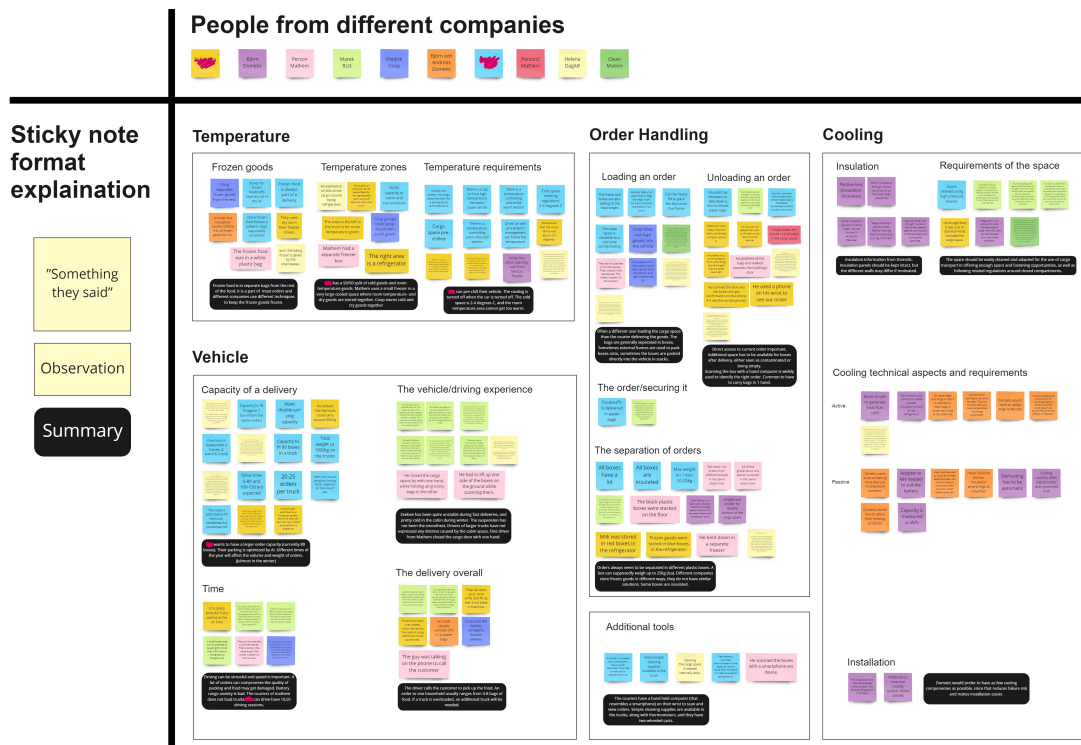


Figure 4.15: Affinity diagram.

**Results:** The affinity diagram resulted in key takeaways (seen as black boxes in Figure 4.15) from the data gathering in the following different areas in this project:

#### *Frozen goods*

Frozen products were found to be part of most orders and was stored in bags separate from refrigerated goods, in separate spaces holding an air temperature lower than  $-18^{\circ}\text{C}$ . The estimated percentage of frozen goods per order varied between being said to be 10 % of an order and being described as 5–6 liters per order. Different companies used different techniques to keep the frozen products at its optimal temperature. Some were seen to utilize one larger, active freezer box. Other used smaller insulated boxes with dry-ice inside.

#### *Temperature zones and cargo space*

There was no clear standardized way to divide colonial, refrigerated and frozen goods

in the cargo space of transport vehicles. However, almost all transport vehicles had their entire cargo spaces cooled, with different solutions for frozen goods. Only one truck had a zone dedicated for colonial goods, being temperature-regulated but not refrigerated. The volume of the cargo space differed, but couriers could enter and stand upright inside of them.

##### *Time and stress*

Most couriers had experienced stress due to delivery time expectations. Speed was important in all steps of the process, with these steps ranging from packing groceries, loading the vehicle and driving to unloading and delivery of goods. The need to pack a lot of orders in a small time frame could compromise the quality of packing. This could result in physical damage on food and packaging. One company's couriers could have driving sessions which resulted in up to 10.5 hours of driving in a single day.

##### *Capacity of a delivery*

The companies that operated with larger planned deliveries generally wanted to continue to use a larger order capacity that could exceed 1000 kg in total weight. Their packing was usually supported by software. The volume and weight of orders as well as share of different types of products were said to vary following the different seasons of the year. An example given was that people ordered a lot of Christmas beverages during the winter. An estimated average of 30% of the volume of an order having a need to be refrigerated and 60% being colonial goods was given, with the last 10% being frozen goods.

##### *Loading and separating an order*

Different staff was generally used for the loading of the cargo space and the driving of vehicles. Every delivery company investigated that utilized paper bags put their bags into plastic boxes, where an average delivery consisted of 6 bags. Some boxes could be insulated, and a box could weigh up to 25 kg. Sometimes, external frames were used to house these boxes inside of the vehicle. Other times the boxes were stacked directly on top of each other. Different methods were utilized to fasten the cargo.

##### *Unloading an order*

Direct access to current orders was important but not always possible. Additional space also had to be available for boxes that had been emptied. A hand computer was used by larger companies to scan plastic boxes in order to identify the correct orders. It was common for the couriers to hold three to four bags in one hand while closing the door to the cargo space with the other. Heavy lifts were required and sometimes boxes and orders could be placed in unwanted locations, such as on the ground.

##### *Thermal energy retention*

All vehicles were insulated and some vehicles utilized plastic strips at the cargo opening to retain cold air.

### *Cleaning and additional tools*

The cargo spaces had to be possible to be cleaned daily. Simple cleaning supplies were available in the trucks, along with thermometers, and a two-wheeled hand truck was available in the delivery vehicle to aid couriers with the delivery of large and heavy orders.

### 4.1.7.2 Intended Use Case for Re:Volt

The market segment of Re:Volt as well as the developed solution implemented as part of it has been identified as being in-between quick commerce and planned deliveries, being more on the side of quick commerce, see section 4.1.3.3. This has been further confirmed through insights gained into the market segment of companies operating within the last mile delivery of groceries, see section 4.1.4. This showed that larger food retailers in the food delivery industry that currently utilize planned deliveries with a larger capacity per delivery round expresses a need for a larger capacity than Re:Volt can offer. Customers operating within quick commerce on the other hand were currently generally utilizing vehicles with an order capacity similar to the one Re:Volt can offer.

The importance of flexibility within the solution to fit different operations and the variety that exist is another area that has been identified through conducted research within user and potential customer studies. An area related to this is the use of pre-packing the goods outside of the vehicle or to load goods directly into the vehicle, see section 4.1.5, where both alternatives have been seen.

### 4.1.7.3 Function tree

**Procedure:** The function tree method described in section 3.8 along with the HTA method described in section 4.1.5.7 were used with the goal of creating an overview over the area that the final solution was supposed to be used in.

**Results:** The method resulted in the function tree that can be seen in Figure 4.16, that consisted of one main function and six part functions. In this project, *offer home delivery transportation* was considered the main function and *offer easy loading*, *ensure product quality*, *ensure energy efficiency*, *offer easy unloading*, *enable sustainability* and *support delivery to door* were the part functions. These part functions were in turn also split up into additional more detailed part functions.

#### 4. Procedures and Results: First Iteration

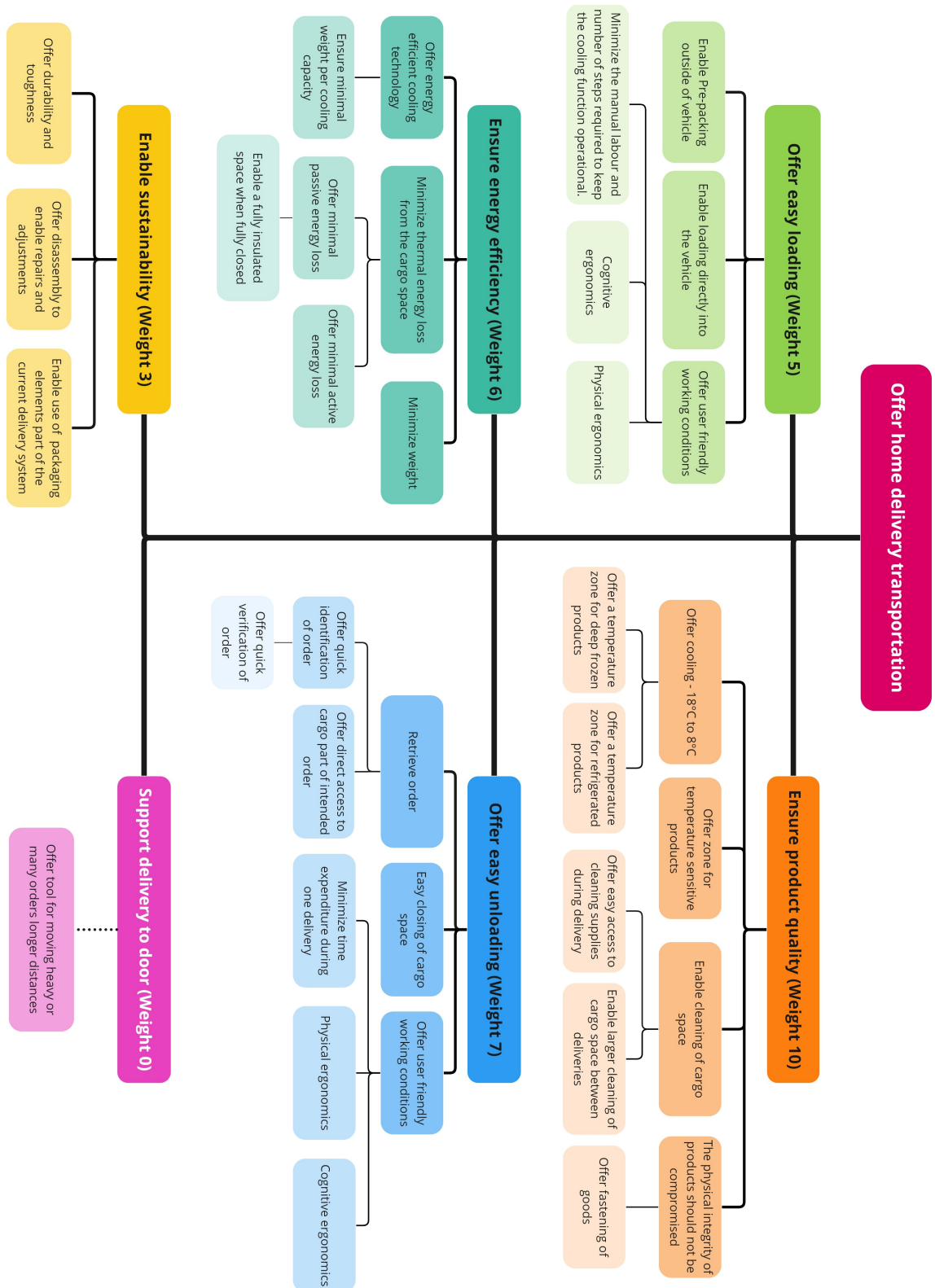


Figure 4.16: Function tree.

#### 4.1.7.4 Adding Weights to the Six Main Part Functions

**Procedure:** The six main part functions in the function tree (Figure 4.16) were stacked against each other in weight criteria matrices (see method 3.9) and can be seen in Figure 4.17. Two of these matrices were made to see if the team had similar views of how important the different part functions were in comparison to each other. The average weighted scores of each function were thereafter used and converted into 1–5 and 1–10 scales.

Alex									
Kriterium	Offer easy Loading	Ensure product quality	Enable sustainability	Ensure energy efficiency	Offer easy unloading	Support delivery to door	Sum	Sum/Tot	(Alex+Amelie)/2
Offer easy Loading		0	1	0.5	0.5	1	3	0.20	0.167
Ensure Product quality	1		1	1	1	1	5	0.33	0.333
Enable sustainability	0	0		0.5	0	1	1.5	0.10	0.083
Ensure energy efficiency	0.5	0	0.5		0	1	2	0.13	0.183
Offer easy unloading	0.5	0	1	1		1	3.5	0.23	0.233
Support delivery to door	0	0	0	0	0		0	0.00	0.000
Tot							15	1.00	1.000

Amelie								
Kriterium	Offer easy Loading	Ensure product quality	Enable sustainability	Ensure energy efficiency	Offer easy unloading	Support delivery to door	Sum	Sum/Tot
Offer easy Loading		0	1	0	0	1	2	0.13
Ensure Product quality	1		1	1	1	1	5	0.33
Enable sustainability	0	0		0	0	1	1	0.07
Ensure energy efficiency	1	0	1		0.5	1	3.5	0.23
Offer easy unloading	1	0	1	0.5		1	3.5	0.23
Support delivery to door	0	0	0	0	0		0	0.00
Tot							15	1.00

Kriterium	Sum/tot	Scale 1-5	Scale 1-10
Offer easy Loading	0.17	3	5
Ensure Product quality	0.33	5	10
Enable sustainability	0.08	1	3
Ensure energy efficiency	0.18	3	6
Offer easy unloading	0.23	4	7
Support delivery to door	0.00	0	0

**Figure 4.17:** Tables that showcase the weight of different functions.

**Results:** The method resulted in the following weights for the following functions:

- Offer easy loading: 5/10
- Ensure product quality: 10/10
- Enable sustainability: 3/10
- Ensure energy efficiency: 6/10
- Offer easy unloading: 7/10
- Support delivery to door: 0/10

#### 4.1.7.5 Requirement list

**Procedure:** Rules and regulations (section 2.1), discussions and semi-structured interviews with Dometic (section 4.1.6.2 and section 4.1.6.3), user and customer studies (section 4.1.4) and discussions with Clean Motion were used to compile requirements lists for the final solution.

**Results:** The resulting requirements for the final solution were divided into six different areas. The areas were: cooling, insulation, physical space, orders, ergonomics, and administrative requirements. All of the requirements are listed in Tables 4.1, 4.2, 4.3, 4.4, 4.5, and 4.6.

**Table 4.1:** Cooling requirements.

Nr.	Requirement	Source of the requirement
C.1	Ensure air circulation around all cargo in the cooled area	Swedish Food Retailers Federation, 2021
C.2	Offer a temperature zone for deep frozen products (air temperature between -24°C and -18°C )	Swedish Food Retailers Federation, 2021
C.3	Offer a temperature zone for refrigerated products (air temperature between 2°C and 4°C )	Swedish Food Retailers Federation, 2021
C.4	Refrigerated products has to be kept at a temperature above 0°C	Swedish Food Retailers Federation, 2021
C.5	Minimize thermal energy loss from the cargo space	Research Phase 1 & Clean Motion
C.6	Cooling technique suitable with battery capacity	Clean Motion

**Table 4.2:** Insulation requirements.

Nr.	Requirement	Source of the requirement
I.1	The cargo space should have a minimum of 30mm polyurethane panels all around it	Dometic
I.2	Minimize thickness of insulation panels	Research Phase 1

**Table 4.3:** Physical space requirements.

Nr.	Requirement	Source of the requirement
P.1	Optimize cargo space utilization with regards to loading capacity and usability	Research Phase 1
P.2	Enable larger cleaning of cargo space	Research Phase 1
P.3	Minimize the vehicle weight	Research Phase 1 & Clean Motion
P.4	Offer durability and toughness	Research Phase 1 & Clean Motion
P.5	Offer adjustable separation of orders	Research Phase 1
P.6	Enable Re:Volt's available cargo weight to be utilized	Research Phase 1 & Clean Motion

**Table 4.4:** Order requirements.

Nr.	Requirement	Source of the requirement
O.1	The physical integrity of products should not be compromised	Research Phase 1 & Swedish Food Retailers Federation, 2021
O.2	Offer identification of orders	Research Phase 1

**Table 4.5:** Physical ergonomics requirements.

Nr.	Requirement	Source of the requirement
E.1	Access to handle of delivery bag	Research Phase 1
E.2	Support ergonomic working positions	Research Phase 1 & The Swedish Work Environment Authority, 2019

**Table 4.6:** Administrative requirements.

Nr.	Requirement	Source of the requirement
A.1	The air temperature of the chilled cargo space have to be logged and saved	Swedish Food Retailers Federation, 2021
A.2	Enable correct measuring and logging of air temperature as well as product temperature	Swedish Food Retailers Federation, 2021
A.3	Offer easy access to cleaning supplies during delivery	Research Phase 1

#### 4.1.7.6 Choice of Cooling Technique: Refrigerated Space of 2°C–4°C

**Procedure:** The identified alternatives for cooling the cargo space to a temperature of 2°C–4°C were the active compressor cooling system 'Frigo DC2500', 'Dometic ColdMachine', active eutectic plates, and passive PCM. These were discussed and compared in order to reach a decision on what cooling technique and corresponding cooling solution was to be chosen for implementation, see Appendix B, section B.1.

**Results:** The chosen cooling technique to refrigerate Re:Volt's cargo space to 2°C–4°C was Dometic Frigo DC2500.

## 4.2 Ideation Phase 1

The first ideation iteration utilizes the insights and ideas gathered during the first research phase and is supported by idea generation through sketching, rapid prototyping, and CAD. The phase resulted in three concepts that were evaluated in Evaluation Phase 1, see section 4.3. The focus during this phase was on the overall structure and the sectioning of the cargo space, mainly affecting the physical structure used to hold cargo.

The aim was to develop a solution that would be feasible to implement into already existing operations similar to those identified in Research Phase 1. It was decided that the solution should strive for utilising off-the-shelf products that would decrease the time and resource expenditure for implementation.

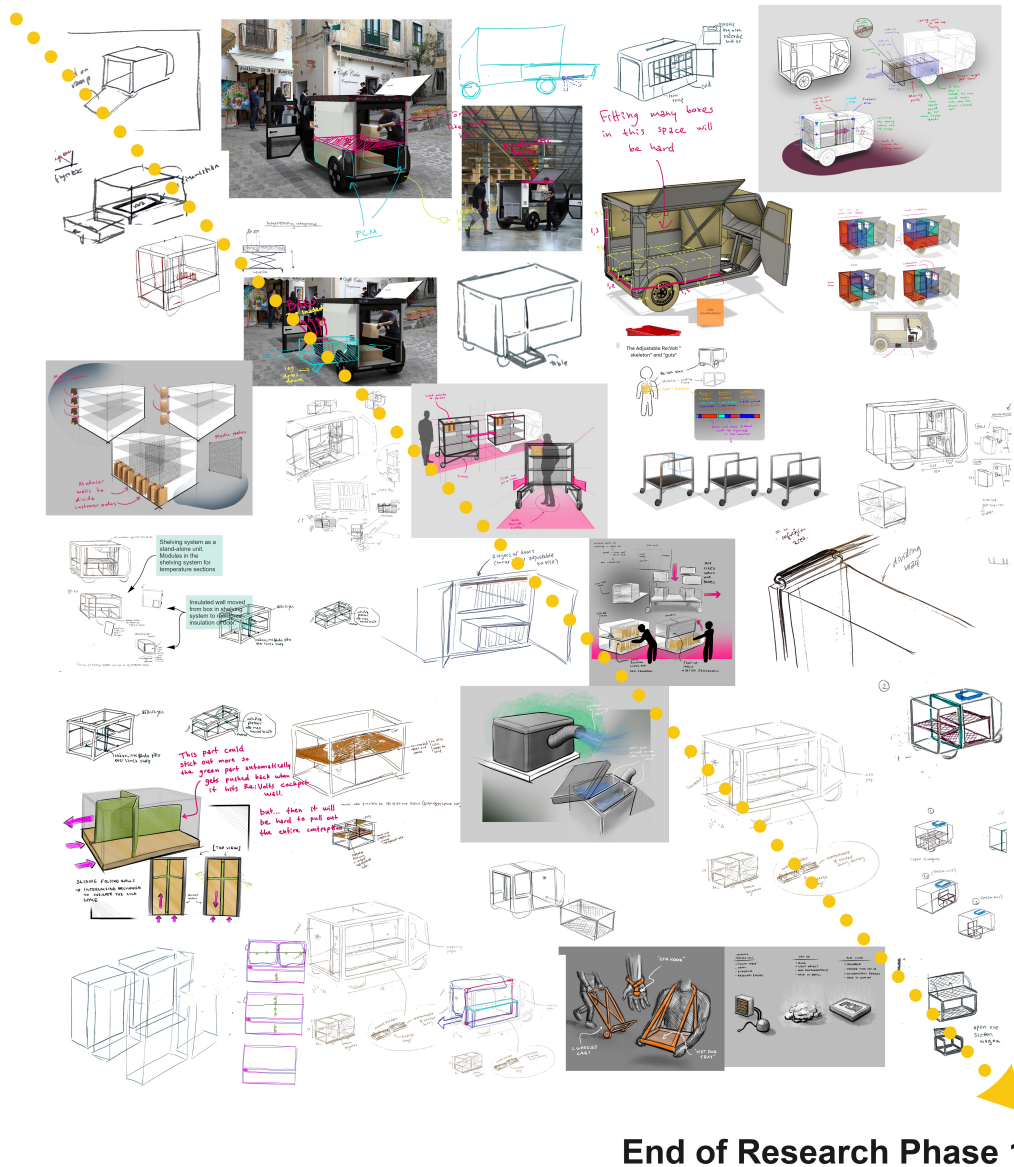
### 4.2.1 Ideation During Research Phase 1

**Procedure:** All throughout Research Phase 1, see section 4.1, ideas spawned on several occasions. These ideas were captured using sketching and short notes, in case the ideas could be found useful at later stages in the development process. All of the sketches were put on a timeline in the online collaboration tool Miro, so that

they could be viewed at any time.

**Results:** The results were many sketches and notes, and about half of them are shown in Figure 4.18.

**Start of Research Phase 1**



**Figure 4.18:** About half of the sketches and notes created during the first research phase, following the chronological course of the phase.

### 4.2.2 Function Tree Second Iteration

**Procedure:** The ideation part of the first research phase, additional research into theory on temperature sensitive products, regulations related to these products during transport as well as observations of common practice in the industry resulted in an updated function tree.

**Results:** When the ideas formed as part of the ideation during the first research phase were analyzed, a realization was made that the aim of having three different temperature zones inside of Re:Volt's cargo space combined with the objective towards an adjustable solution would add a lot of complexity.

It is commonly seen in the last mile delivery part of the food transport industry today that the two temperature zones offered during transport are refrigeration and freezer. In these cases, it has been observed that more sensitive products are additionally insulated using paper bags, see section 4.1.5.5. Additional research into temperature requirements of potentially sensitive products such as vegetables was also made, in section 2.1.3. One finding was that the vast majority of common vegetables could handle refrigerated temperatures. Industry guidelines also saw it as acceptable to store more sensitive products such as warm vegetables together with other products for shorter periods of time during transport if necessary.

Based on this, a decision was made to alter the function tree, see Figure 4.19. The main changes being to move the function regarding offering a temperature zone for temperature sensitive products from the part function: *ensure product quality*, to the part function: *supportive functions*. As a consequence, this function was no longer prioritized as highly compared to before. Other smaller alterations were also made, such as splitting up sub part functions to be more defined.

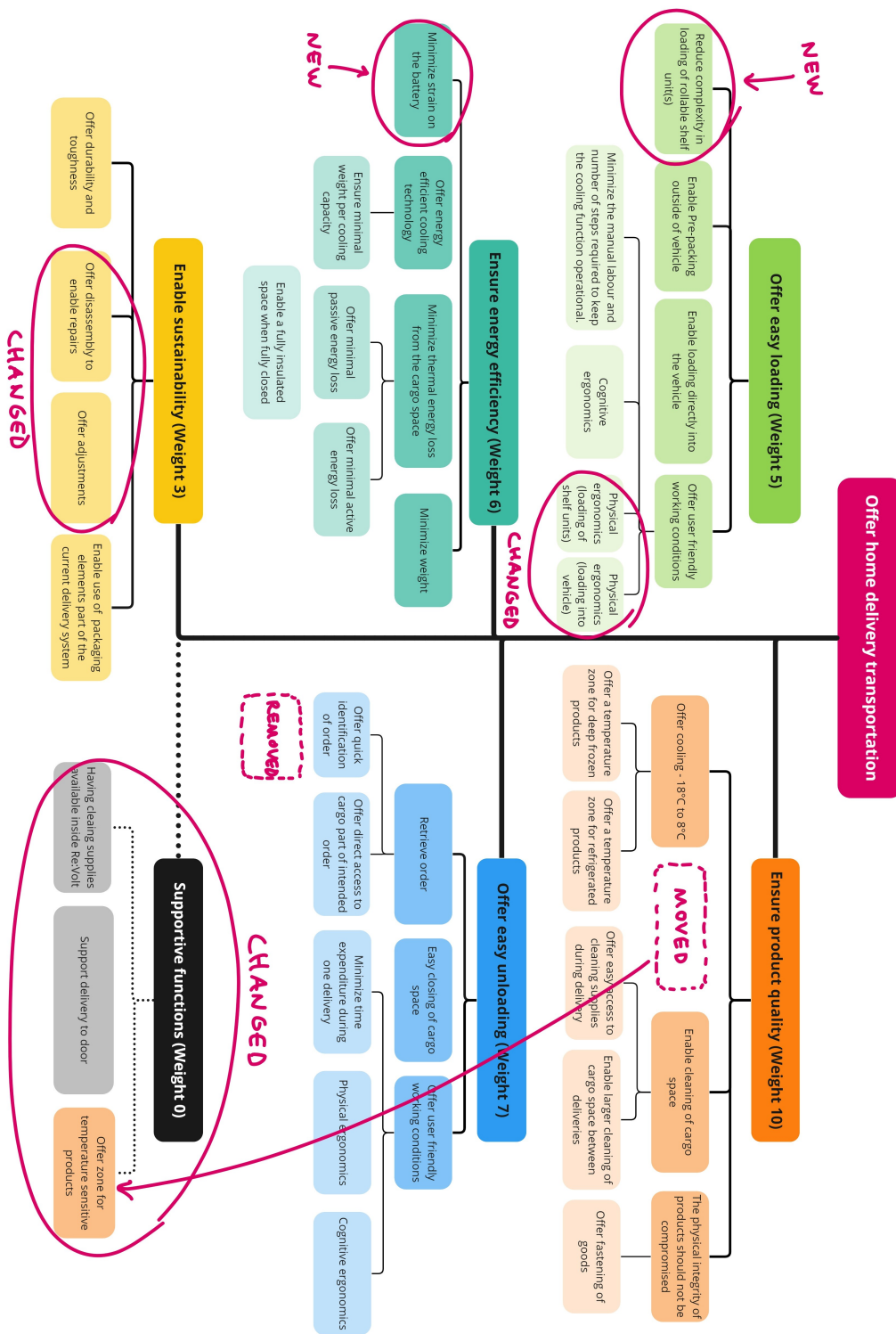


Figure 4.19: Updated function tree, second iteration.

### 4.2.3 Ideation and Sketching Session for Part Solutions

**Procedure:** A session was dedicated to discuss and sketch solutions for the desired functions identified in section 4.2.2. This was also based on insights from the

ideation part of Research Phase 1, see section 4.2.1 as well as what had been identified as available solutions on the market through user and customer studies.

**Results:** A number of sketches and ideas were gathered for each part function of the function tree. It was found that it would be beneficial to put the focus for this first ideation iteration on the overall physical structure of the interior of the cargo space, with a stronger focus on the part function *Offer easy loading* also taking the part functions of *Offer easy unloading* and *Ensure product quality* into account. This choice of focus was based in the increasingly added complexity of including all detail levels at once in the concept creation. The lower level of detail in the overall structure of the space was found to be a suitable starting point.

### 4.2.3.1 Part Solutions to Offer Easy Loading, Ensured Product Quality and Easy Unloading

To offer easy loading, the solution space mostly covered different alternatives for the division of the cargo space overall, both horizontally and vertically, as well as how to offer a solution that could be used continuously from the packing of the goods in paper bags to the packing of the paper bags in the cargo space.

The solution space for ensuring product quality mainly focused on the ability to fully clean the equipped cargo space as well as looking at available alternatives for providing a temperature zone for frozen products and how that could fit in the overall structure of the cargo space as well as being easily accessible.

Related to the offering of easy unloading, the area of direct access to an intended order as well as easy organisation of paper bags part of an order where investigated but then decided to be on a too detailed level to be addressed in the first ideation iteration. The focus was then instead put on the impact the overall structure of the solution had on the physical ergonomics of the user when unloading goods.

### 4.2.3.2 Number of Shelves in the Cargo Space

It was early identified, mainly during the user studies (see section 4.1.5), as beneficial to implement some kind of shelf in order to utilize the height in the cargo space while not blocking access to a large part of the cargo. The number of shelves in the cargo space is an aspect that has a large influence on the overall structure of the solution. The identified paper bag size of 34x17x33 cm was used as a starting point, see section 4.1.4.5. It was mainly the height of 33 cm that was seen as relevant. This resulted in the possible number of shelves in the cargo space being two or three, see Figure 4.20. The number mainly affected functions related to the offering of easy loading and unloading of goods.



**Figure 4.20:** Comparison of how two or three levels of shelves carrying paper bags would fit inside the cargo space of Re:Volt.

The main argument for choosing to implement three shelves in the cargo space was to maximize the capacity of orders. This was mainly an identified wish from operations within planned deliveries, where all orders were also usually packed outside of the vehicle. Several negative aspects related to the implementation of three shelves were identified. One was how it could result in a less ergonomic working situation, both when loading and unloading orders. This would mainly be because the decrease of the opening between two shelves where paper bags were supposed to be placed, as well as decreasing the space above the paper bag where the user had to access the handle of the bag during unloading. The physical ergonomics of the loading and unloading of orders was also negatively affected through how a third shelf would result in lifts from a higher height. Another negative aspect with using three shelves was how it would interfere with the cooling system in the refrigerated area. This could result in some paper bags colliding with the evaporator unit, as well as posing the risk that more sensitive products get placed just in front of the cold air exhaust from the evaporator unit. A third shelf would also reduce the oversight a user can have over the orders in the cargo space overall, and limit the available packaging alternatives to not include for example taller paper bags, which was utilized by some actors in the industry.

Based on this, the decision was made to continue developing a solution implementing two horizontal shelves, splitting the cargo space into two similarly sized parts with one lower shelf a few centimeters above the floor to support good air flow and an upper shelf in the middle of the cargo space at a height of around 60 cm above the

floor.

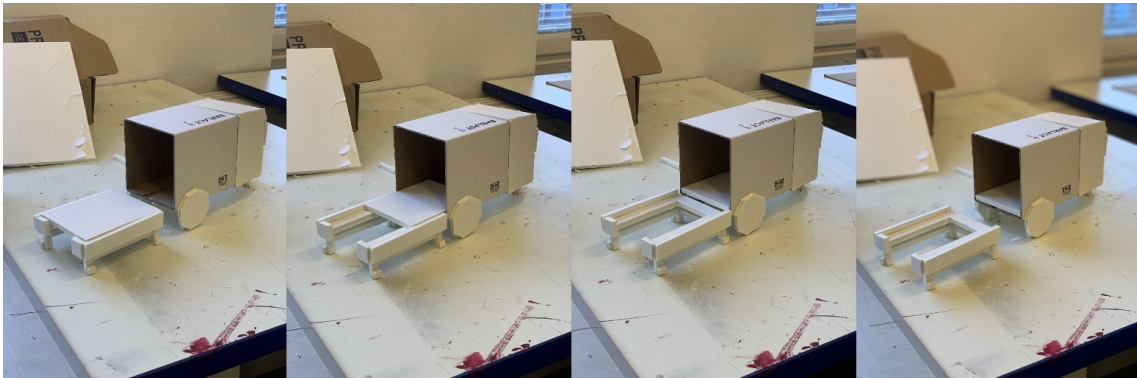
### 4.2.4 Quick Prototyping

Large and small scale prototypes and mock-ups were used to get a better spacial understanding of Re:Volt's cargo space.

#### 4.2.4.1 Small Scale Cardboard Prototyping

**Procedure:** One session of utilizing smaller cardboard boxes and a lightweight foam board as an alternative way to sketch ideas. The focus was on the feasibility of moving elements, by getting a feel for the solution in 3D.

**Results:** The prototyping session resulted in a small physical mock-up of the concept of having a structure that could be support the loading and unloading of a larger shelf structure from the cargo space of Re:Volt, see Figure 4.21. The solution space of movable walls and shelves in relation to the structure was also explored.

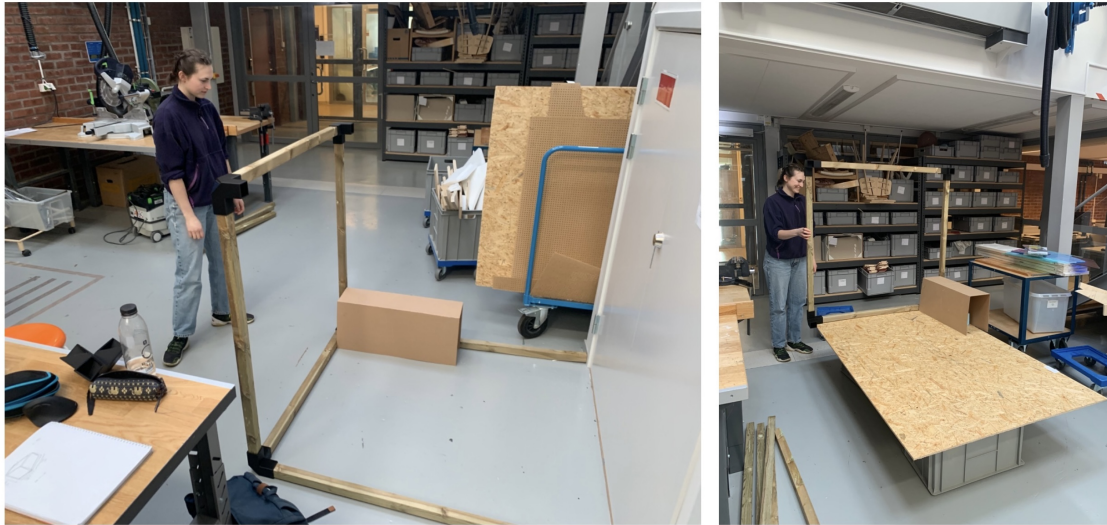


**Figure 4.21:** Smaller cardboard mock-up of Re:Volt and a separate transportation dolly to support loading and unloading of the larger shelf unit.

### 4.2.5 Large Scale Re:Volt Mock-up

**Procedure:** To support the spatial perception of the cargo space of Re:Volt a full scale (1:1) frame representing the cargo space was set up using wooden studs and 3D printed corners to joint them together.

**Results:** The prototyping session resulted in a strengthened perception of both the size and the ratio of dimensions to which the product must adhere, see Figure 4.22. A cardboard was added to the frame to represent the dimensions of one of the wheel houses that will affect the size of the back opening of the cargo space.

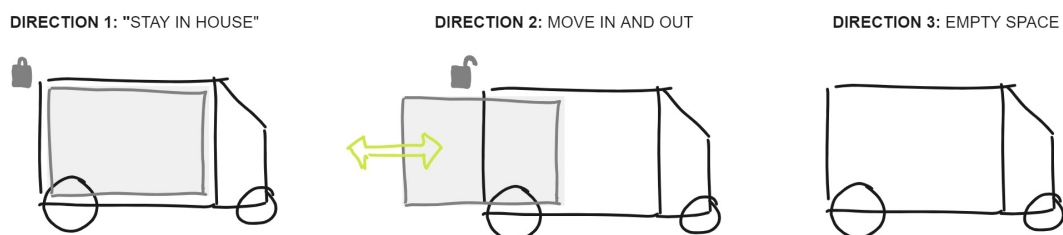


**Figure 4.22:** A quick 1:1 mock-up of the height and width of Re:Volt’s cargo space, the picture on the left representing the length of the cargo space and the picture to the right representing the floor height, the total height and the width of the cargo space.

#### 4.2.6 Exploring and Choosing an Overall Concept Direction

**Procedure:** In order to explore relevant concept directions, the results of previous ideation, see section 4.2.3 were utilized. This resulted in three different concept directions divided into six variations. These were then separately evaluated, reaching a conclusion to proceed development with one out of the three concept directions.

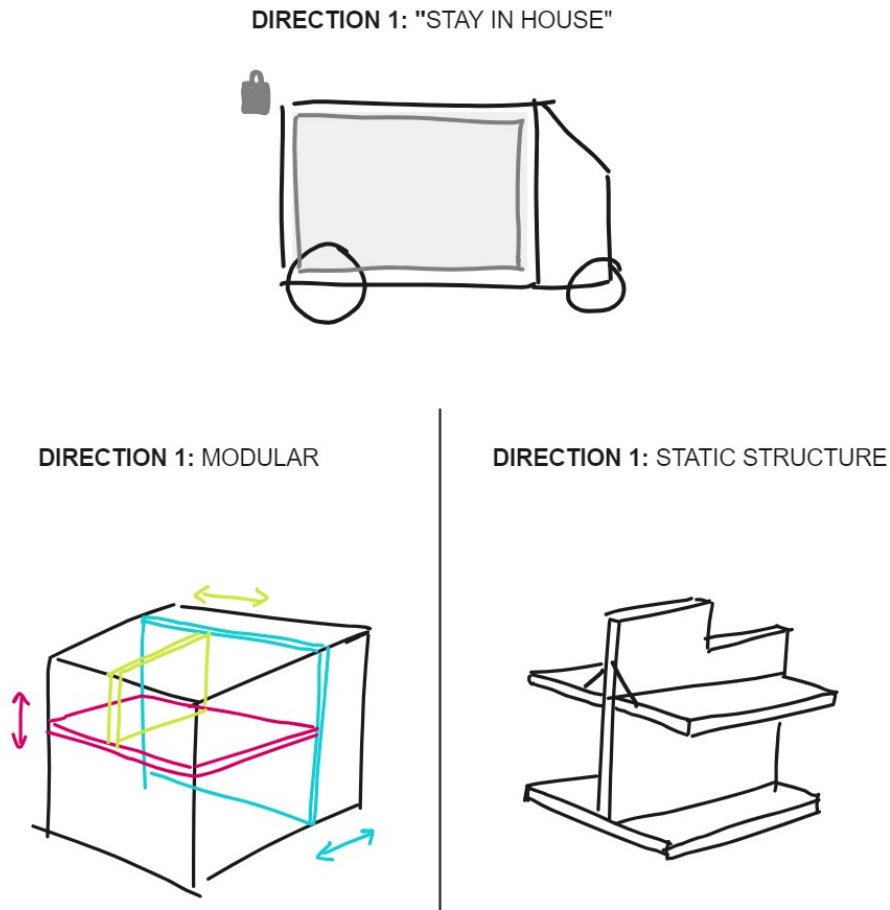
**Results:** In section 4.2.3, the ideas revolved around a structure inside of Re:Volt that could function in two different ways. One way was to have the structure permanently installed and the other way was to have it be removable from Re:Volt’s cargo space. A third option was also identified, which would be to keep the cargo space completely empty. These three different directions were called: ‘Stay in house’, ‘Move in and out’, and ‘Empty space’, see figure 4.23.



**Figure 4.23:** Three different concept directions.

#### 4.2.6.1 Concept Direction 1: Permanently Installed Shelf Structure

Two variations were identified as part of having a permanently installed shelf structure, see Figure 4.24. One was to introduce movable elements, thus resulting in a modular shelf, and another was a fully static structure.



**Figure 4.24:** Concept direction: Permanently installed shelf structure.

##### *Positives with a permanently installed shelf structure*

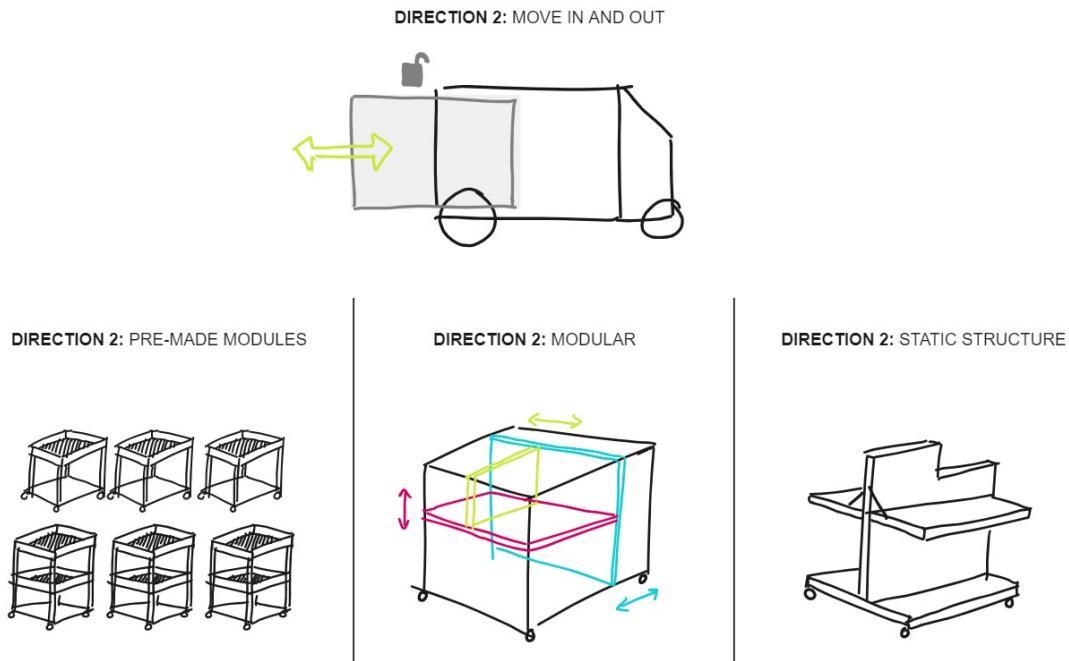
- + Suitable for quick commerce and loading paper bags directly into the vehicle.
- + Low complexity, potentially resulting in a more simple production process.
- + Likely to require slightly less material, reducing cost and weight.

##### *Negatives with a permanently installed shelf structure*

- Less suitable for planned deliveries that require pre-packing of orders.
- Less easy to alter after production.
- Difficult to clean the cargo space.

#### 4.2.6.2 Concept Direction 2: Movable Shelf Structure

Three possible variants were identified as part of having a shelf structure that can be moved in and out of the cargo space, see Figure 4.25. Them being to have the structure being made up of several smaller modules, a movable structure being modular and a static structure being movable.



**Figure 4.25:** Concept direction: Movable shelf structure.

##### *Positives with a movable shelf structure*

- + Suitable for quick commerce (can be left in or taken out of the cargo space).
- + Suitable for planned deliveries (can be left in or taken out of the cargo space).
- + Possible to use in the same way as the discussed concept direction of having a permanently installed shelf structure.
- + Easier to adjust after production (can exchange parts of the movable unit or replace it fully).
- + Easy to clean the cargo space.

##### *Negatives with a movable shelf structure*

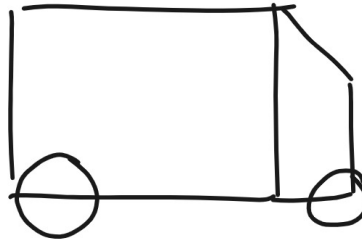
- Likely to require slightly more material, which increases cost and weight.
- Slightly higher complexity, potentially resulting in a more advanced production process.

#### 4.2.6.3 Concept Direction 3: An empty Cargo Space

Keeping the cargo space empty was included to evaluate what some positive and negative aspects were of not inflicting on the cargo space at all, as a way to validate

that a continued development of an additional shelf structure would be beneficial.

### DIRECTION 3: EMPTY SPACE



**Figure 4.26:** Concept direction: Empty space.

#### *Positives with an empty cargo space*

- + Easy to clean.
- + Low cost.
- + No additional manufacturing required.
- + Easy to adjust after production.

#### *Negatives with an empty cargo space*

- Not suitable for planned deliveries that require pre-packing of orders.
- Requires additional products to divide orders, such as plastic boxes.
- Requires additional products (such as boxes) to house orders on top of each other without damaging groceries.
- Poses a challenge to fasten the goods in a satisfactory way.
- No direct access to goods at the bottom of stacked cargo.
- Could result in a non-optimal working situation for the user from a physical ergonomics perspective during loading and unloading, for example, through not offering direct access to the intended order.
- Less refined product to offer.

#### 4.2.6.4 Choosing a Concept Direction

*Concept direction 2* was chosen for further development in the project. It was found that a movable solution could fulfill many of the customer and user needs that the permanently installed shelf structure in *concept direction 1* could meet. The additional flexibility and manoeuvrability with a movable shelf structure was also found to be positive. Therefore, all three variations within *concept direction 2* of having a movable shelf structure was kept in order to not limit the solution space before investigating it further. These three variations were the usage of pre-made modules, a modular structure and a movable static structure.

The decision of eliminating *concept direction 3*, 'An empty cargo space', was based on the many negative aspects identified in that concept direction, where many could be seen as central to the usability of the product.

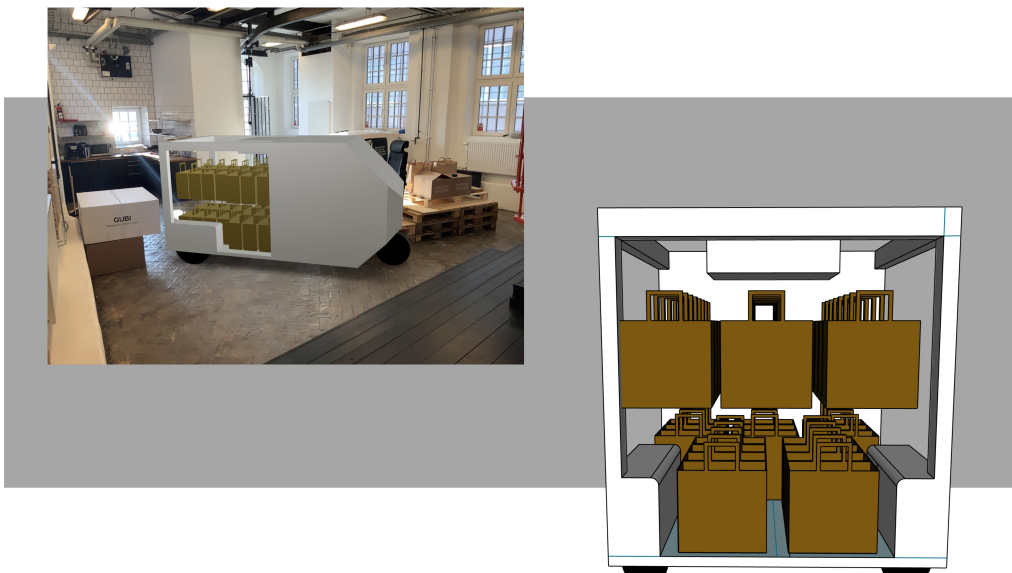
#### 4.2.7 Development of Concept Direction 2: Movable Shelf Structure

The starting point of the further development of the concept direction 2: a movable shelf structure, was to create of a simplified CAD model of Re:Volt. The aim of this was to understand how goods in the cargo space could be configured and distributed in relation to accessibility and capacity when ideating around the design of shelf units part of the solution for the cargo space.

##### 4.2.7.1 CAD Representation of Re:Volt

**Procedure:** At the time, Re:Volt did not have fully determined measurements, but the temporary measurements of its cargo space was used in combination with representations of the identified standard paper bag in order to create a CAD representation of the vehicle Re:Volt and its cargo space filled with goods.

**Results:** The result was a simplified CAD model of Re:Volt, see Figure 4.27. This was used as a foundation for the following development of three concepts incorporating movable shelf units.

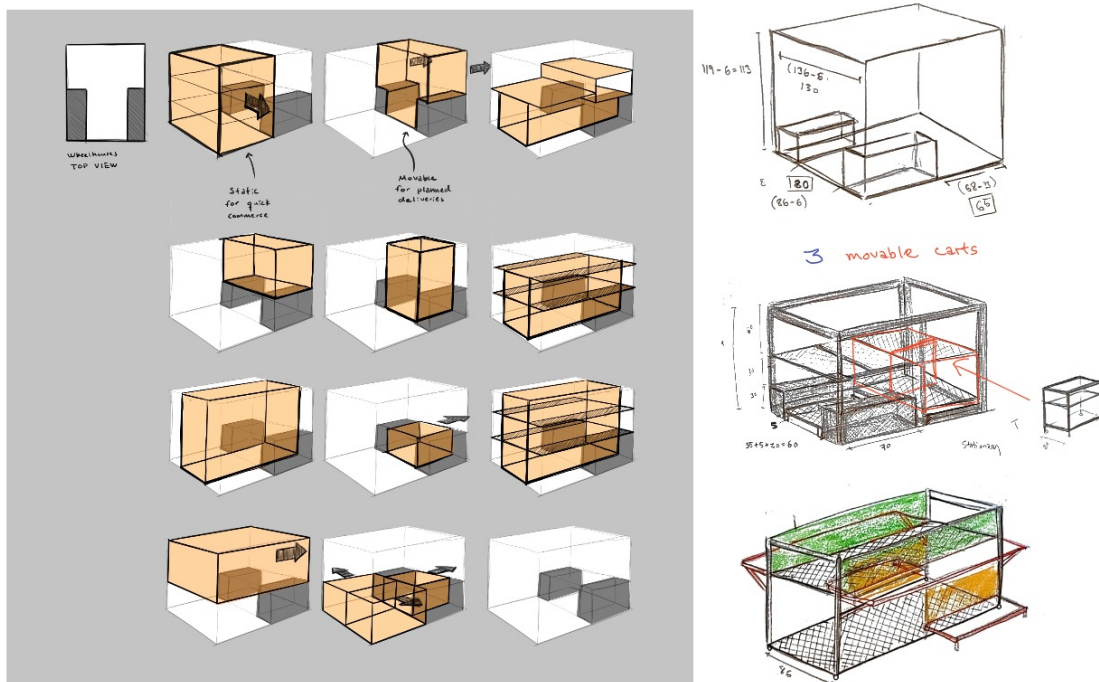


**Figure 4.27:** Simplified CAD model of Re:Volt, including goods in the form of bags.

#### 4.2.7.2 Ideation of the Shelf Structure Design

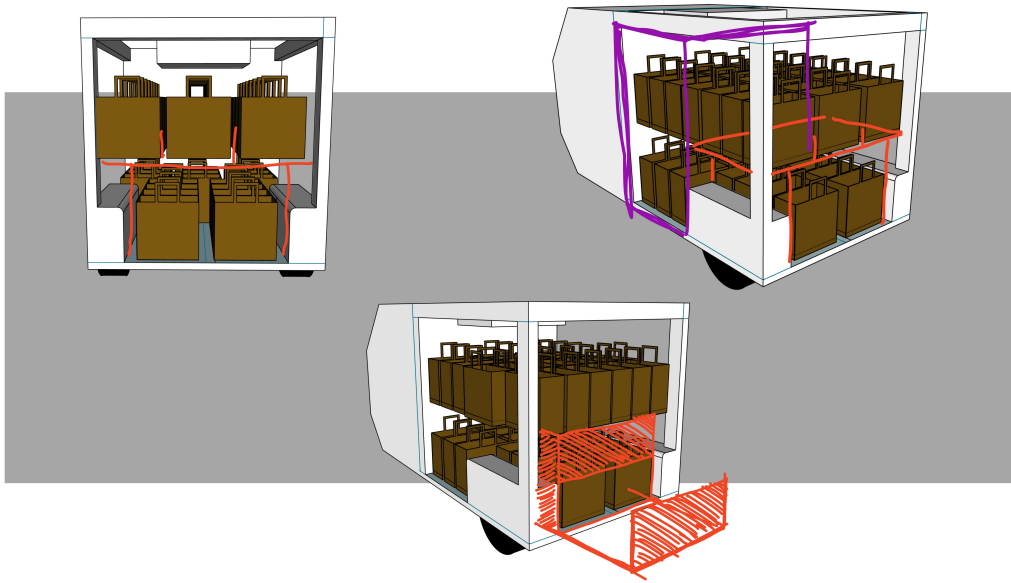
**Procedure:** Sketching as well as sketching in combination with simple CAD representation of the cargo space filled with goods in the form of paper bags were utilized in order to ideate around the design of the shelf structure used to hold goods in the cargo space. The aim was to investigate the solution space of concept direction 2 further, putting focus on the utilization of the cargo space volume in relation to ease of loading and unloading of goods.

**Results:** In order to investigate the design of the shelf structure, some available configurations of partitions as well as shelves regarding the utilization of the space in relation to how to access it were sketched, see Figure 4.28.



**Figure 4.28:** Sketches of different partitions inside the cargo space of Re:Volt as well as possible shelf structures.

To further support the exploration of a solution possible to implement in the cargo space of Re:Volt, the CAD representation of Re:Volt filled with cargo was utilized as a basis for some sketches, see Figure 4.29.



**Figure 4.29:** Sketches using the CAD representation of Re:Volt filled with cargo in the form of paper bags as support.

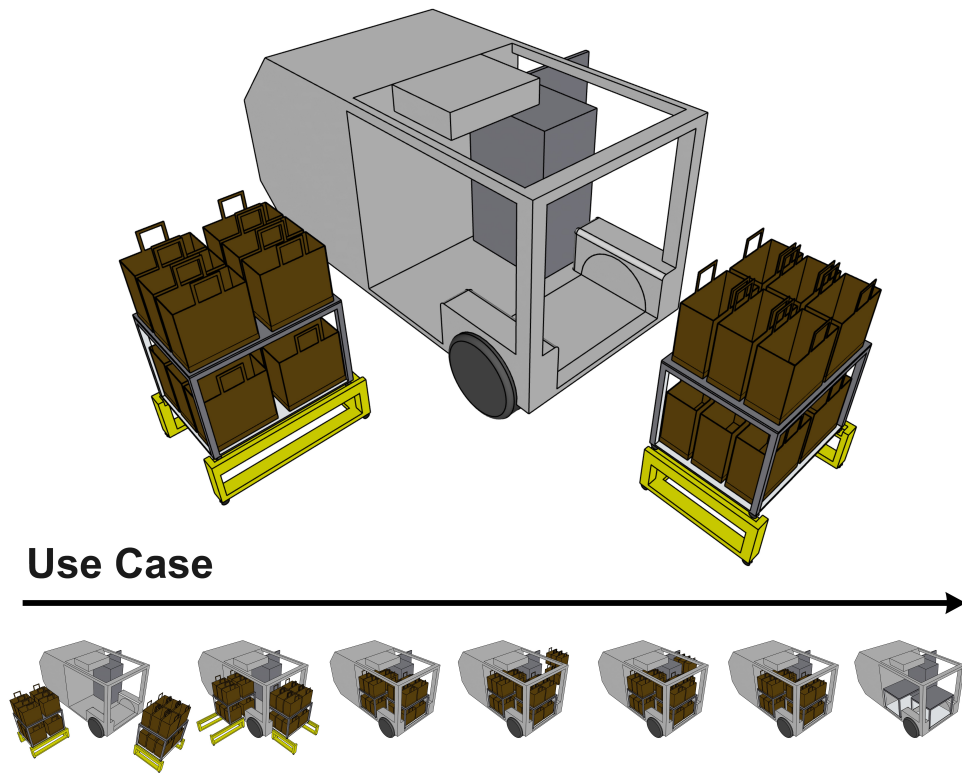
## 4.2.8 Resulting Three Concepts from Ideation Phase 1

**Procedure:** As with the development of the chosen concept direction, the creation of three concepts of Ideation Phase 1 put focus on a selection of the functions in the function tree, see section 4.2.2. These functions were *Offer easy loading*, *Offer easy unloading* and *Ensure product quality*. Also considering the part solutions explored for these functions in section 4.2.3. One objective of the concept creation was to aim towards differentiating the concepts from each other, to support identifying different positive and negative aspects in and between the concepts.

**Results:** The result of Ideation Phase 1 was three concepts, named Concept A, Concept B and Concept C.

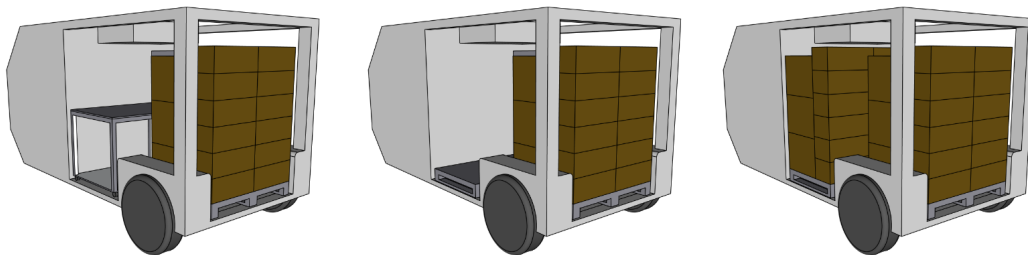
### 4.2.8.1 Concept A: Twins

Concept A consisted of two identical shelf units on wheels, which could be rolled around outside of the vehicle on a transportation dolly visualized in yellow, see Figure 4.30. It also contained a permanently installed active freezer. One shelf unit would be loaded from the side of the vehicle and one shelf unit would be loaded from the back. In this concept, 30 bags could be housed in total in the cargo space. Of which 24 could be loaded outside the vehicle, and 6 bags could be loaded directly into the freezer.



**Figure 4.30:** Concept A.

A variation of Concept A can be seen in Figure 4.31, where one or both of the shelf units could be replaced with standardized half pallets.

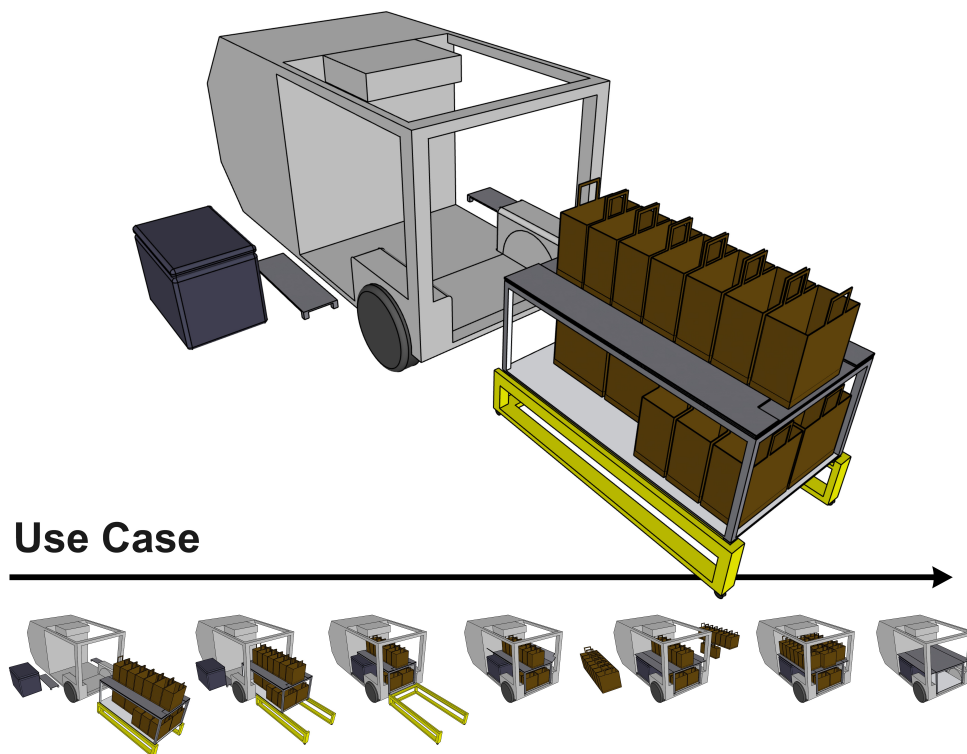


**Figure 4.31:** Concept A: pallet variation.

#### 4.2.8.2 Concept B: The Unit

Concept B consisted of one large shelf units on wheels, that could be rolled around outside of the vehicle on a transportation dolly represented in yellow, see Figure

4.33. Two shelves along the long side of the shelf structure was foldable so that the upper shelf could be extended outwards when being inside the cargo space. The concept included two small pads that were secured in front of the wheel houses, so bags and a freezer box utilizing dry-ice could be placed leveled with the bottom shelf of the movable unit. In this concept, 38 bags could be housed in total in the cargo space. Of these 20 bags could be loaded outside of the vehicle, whereof 3 bags could be stored in a freezer space.



**Figure 4.32:** Concept B.

#### 4.2.8.3 Concept C: Semi Static

Concept C consisted of one movable shelf unit on wheels, that could be rolled around outside of the vehicle on a transportation dolly represented in yellow, see Figure 4.32. The unit itself consisted of three smaller units, one of which would be replaced with a freezer unit that contained a PCM block. Additionally, it had a permanently attached shelf in the back of the vehicle. In this concept, 38 bags could be housed in total in the cargo space. Of these, 18 bags could be loaded outside of the vehicle of which 3 could be stored in a freezer space.

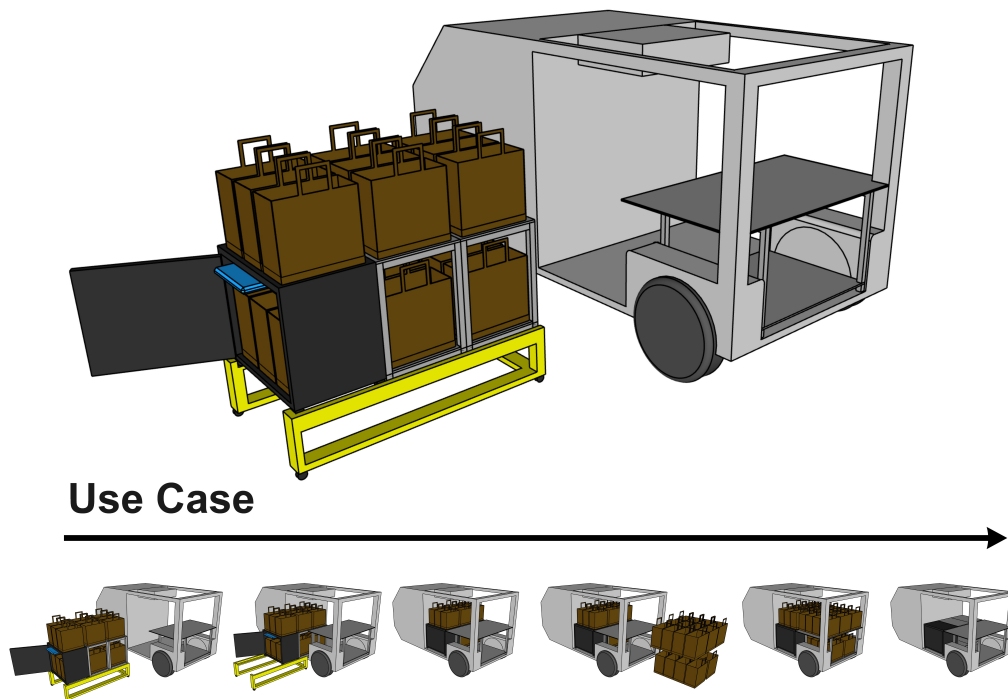


Figure 4.33: Concept C.

## 4.3 Evaluation Phase 1

The main goal of the first evaluation phase was to get external input from project partners on the concepts being: Concept A, Concept B and Concept C, that were created in Ideation Phase 1, see section 4.2. Other areas included in this first evaluation phase was to evaluate some aspects related to ergonomics regarding Re:Volt doors and openings as part of a users' interaction with the cargo space.

### 4.3.1 Ergonomic Evaluation of Re:Volt's Initial Side Panels

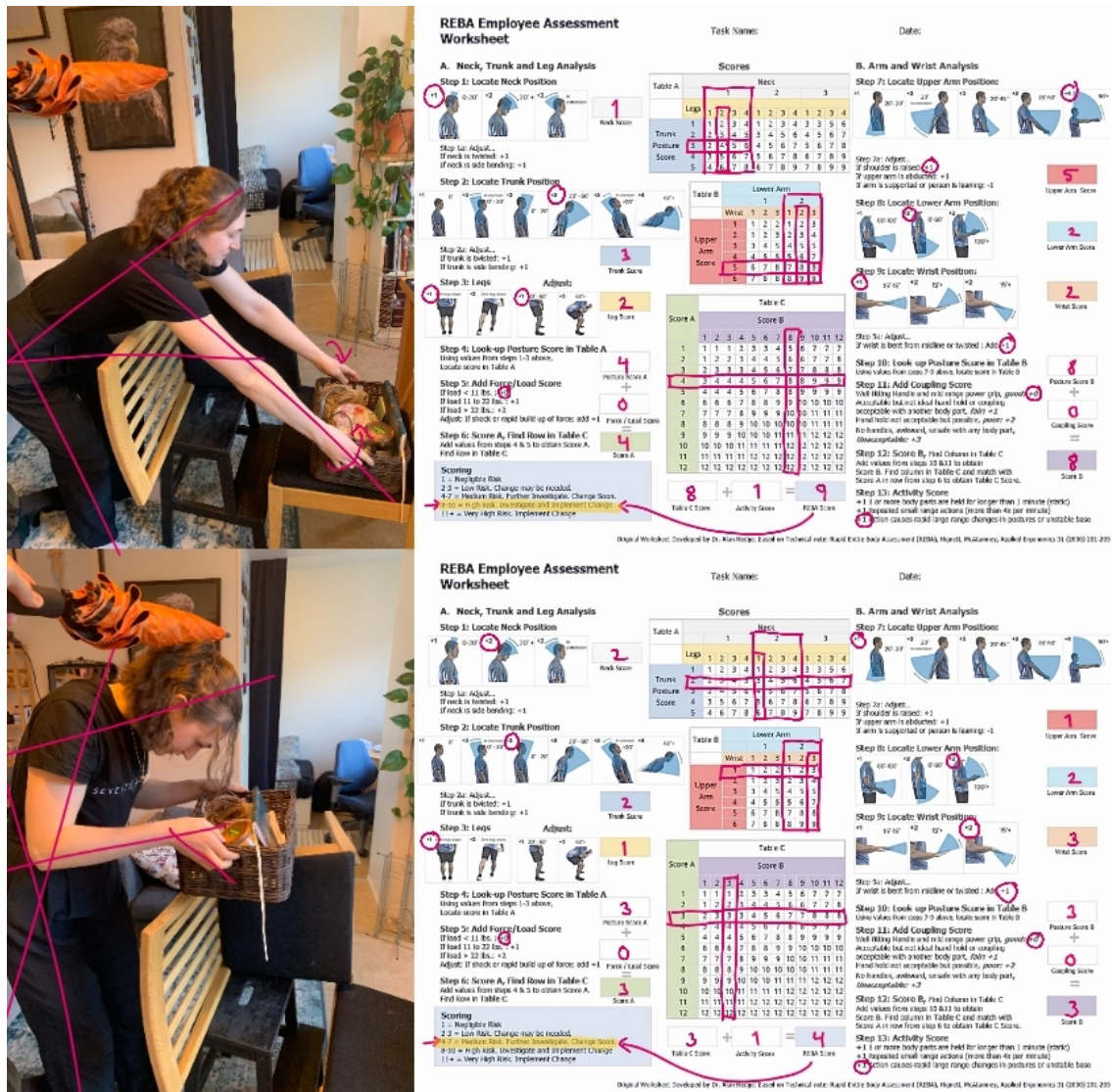
**Procedure:** Early in the project a potential problem was identified regarding the preliminary side panels on Re:Volt (see Figure 4.34) related to the physical ergonomics of the user during loading and unloading of goods. A REBA analysis, described in section 3.5, was therefore conducted on a simple 1:1 scale mock-up composed of chairs, an umbrella, and a basket. The aim of this was to evaluate the side panel from the perspective of the potential problem identified.



**Figure 4.34:** The initial design of Re:Volt with static, lower side panels visualized in green.

**Results:** See Figure 4.35 for the setup and results of the REBA analysis conducted on a simple 1:1 scale mock-up composed of a chair to represent the side panel and the floor of the cargo space, an umbrella to represent the top of the opening to the cargo space and a basket representing the package to be collected. The task explored was the user reaching in to collect something from the cargo space behind a side panel.

## 4. Procedures and Results: First Iteration



**Figure 4.35:** Two REBA analysis conducted on a scenario that could occur where the user reaches in to collect some goods from the cargo space, using a simple 1:1 scale mock-up of Re:Volt’s side panel and side opening.

The stretched out position that occurred while grabbing a package far into the cargo space resulted in a REBA score of 9, which meant that the position was of high risk, and that it needed to be investigated so that change could be implemented. Moreover, the consequent position that occurred right at the end of the movement before the courier could move away from the vehicle, resulted in a REBA score of 4 which meant that it was a medium risk position. This position should also be investigated and changed.

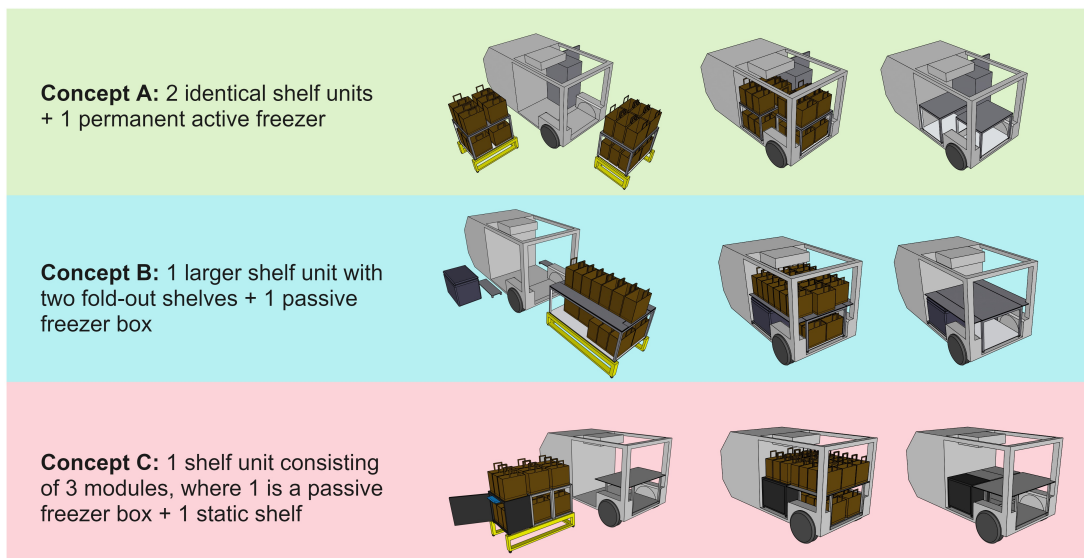
### 4.3.2 Half Time Presentation for Clean Motion

**Procedure:** When the mid point in the project was passed, a presentation was made to Clean Motion which showed the progress of the project so far. This, along with a dialogue during visits to their office was used to get feedback on Concept A,

Concept B and Concept C.

**Results:** The three concepts Concept A, Concept B and Concept C was discussed with representatives from Clean Motion, see Figure 4.36. Clean Motion thought that the rollable shelf units outside of Re:Volt would be beneficial since it could shorten the loading times of goods such as groceries. It was believed that a single rollable unit, such as the one in Concept B would be preferred over having multiple rollable units such as in Concept A based in the added complexity of the loading situation. Connected to this was the feedback that the amount of goods in the form of paper bags possible to load onto the unit outside of the vehicle should be maximized in order to limit the time required during loading of the vehicle. Lastly, it was believed that a removable freezer box such as in Concept B and Concept C would be a more flexible solution than a permanently installed freezer compartment like in Concept A.

### All Concepts



**Figure 4.36:** The tree concepts, presented to people at Clean Motion.

### 4.3.3 Feedback Dialogue with Operations Manager at Picmart

**Procedure:** During the first meeting with an operations manager at Picmart (see section 5.1.1.1), Concept A, Concept B and Concept C were shown to get input on the concepts from a potential customer active in a market segment covering both quick commerce and planned deliveries. This input was intended to be used as part of the future development of the concepts.

**Results:** Only positive feedback was received on what was shown in the concepts and it was said that Picmart needed solutions similar to the ones shown. The

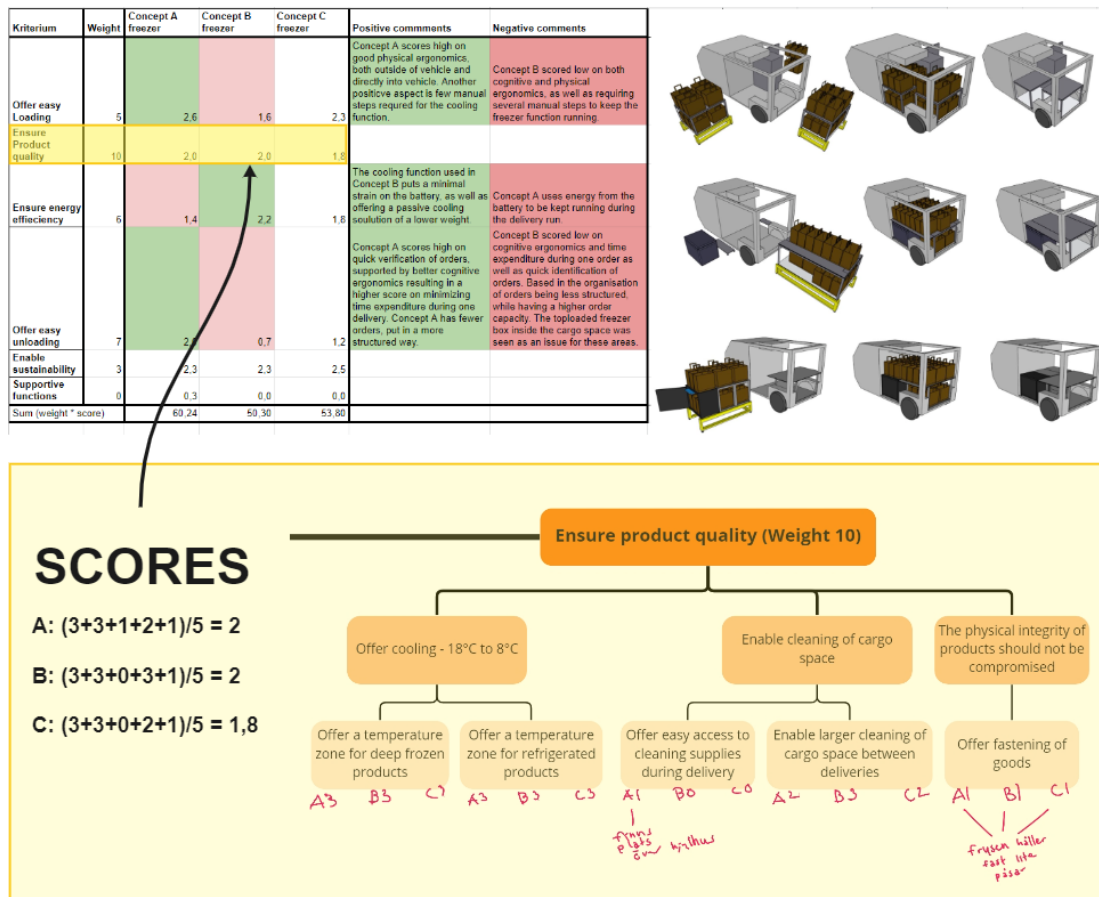
operations manager said that real problems and needs had been identified and that the project showed a high understanding of what the last mile delivery situation looks like. It was mentioned that Picsmart did not always have the need to pre-load all orders of groceries on the shelf structure outside of their vehicle. The main reason for this was that they do not always deliver a large number of orders at once. The loading situation is also said to vary, sometimes involving having to walk down stairs to get from the grocery store to the delivery vehicle. Therefore, in those situations it was said that it was motivated to leave the shelf unit inside of Re:Volt instead of taking it out in-between every delivery trip. Lastly, the operations manager said that the size of Re:Volt and the estimated amount of orders the concept presented could handle was a great fit for the use case of Picsmart.

### 4.3.4 Concept Comparison Matrix

**Procedure:** Concept A, Concept B and Concept C, were compared against each other in a concept comparison matrix (see method in section 3.10). However, instead of immediately giving the concepts a score of 0–3 for each criteria, the lowest level of sub-criteria of the criteria was scored. The reasoning behind this was that all criteria had many factors that had to be taken into account, with the use of scoring the sub-criteria being seen to give a more nuanced result. Therefore, the smallest sub-criteria were given a score of 0–3 for each concept, and their scores were summed up and divided by the amount of sub-criteria to get a final score for each criteria. The final scores for each criteria and concept were then placed in the concept comparison matrix. Some comments were also added for the reasoning behind certain scoring decisions in order to support further development of the concepts.

**Results:** For the results of the creation of the concept comparison matrix, see Figure 4.37. A relatively high score for a criteria was marked as green and a relatively low score was marked as red. In these cases, comments were made on what was identified as reasons for the relatively higher or lower score.

## 4. Procedures and Results: First Iteration



**Figure 4.37:** Concept comparison matrix of the three concepts being results of Ideation Phase 1.

Concept A got a score of 60.2, Concept B a score of 50.3, and Concept C a score of 53.8. Positive and negative aspects of Concept A (that scored the highest) and Concept B (that scored the lowest) were summarized in the following list:

### Comments Concept A

- Concept A scored high on good physical ergonomics, both outside of vehicle and directly into vehicle. Another positive aspect were that few manual steps were required for the cooling function.
- Concept A scored low on ensure energy efficiency, using energy from the battery to be kept running during the delivery run.
- Concept A scored high on quick verification of orders, supported by better cognitive ergonomics resulting in a higher score on minimizing time expenditure during one delivery. Concept A has fewer orders, put in a more structured way.

### Comments Concept B

- Concept B scored low on both cognitive and physical ergonomics, as well as requiring several manual steps to keep the freezer function running.
- Concept B scored high on ensuring energy efficiency, with a cooling function putting a minimal strain on the battery and offer a passive cooling solution of

a lower weight.

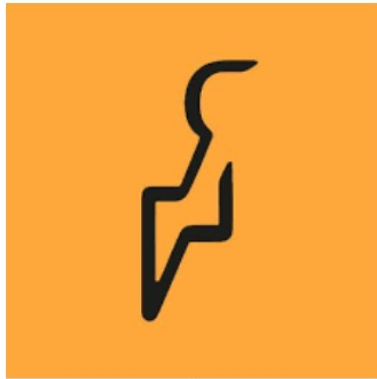
- Concept B scored low on cognitive ergonomics and time expenditure during one order as well as quick identification of orders. Based in the organisation of orders being less structured, while having a higher order capacity. The top loaded freezer box inside the cargo space was seen as an issue for these areas.

### 4.3.5 Summarized Results of Evaluation Phase 1

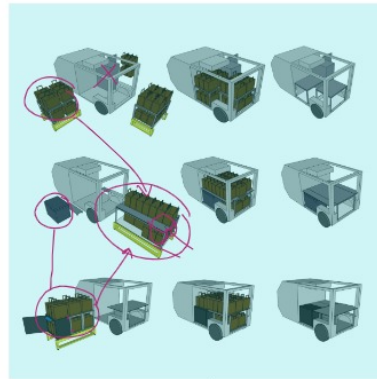
**Procedure:** The results of the first evaluation phase, mainly the half time presentation with Clean Motion (see section 4.3.2) and the concept comparison matrix (see section 4.3.4) were summarized to evaluate and conclude what the future direction of the concept development would be. In order to define this direction, a new concept was created as a result of Evaluation Phase 1.

**Results:** Figure 4.38 illustrates the resulting concept that would act as a starting point in the next ideation phase. One key point of this concept was that Re:Volt should be loaded into the cargo space as one unit from one direction. Other points were that it is important to minimize loading and unloading times, to implement a flexible freezer solution and to enable pre-packing of orders outside of the vehicle to a maximum degree.

Feedback after presentation  
for Clean Motion 6/4

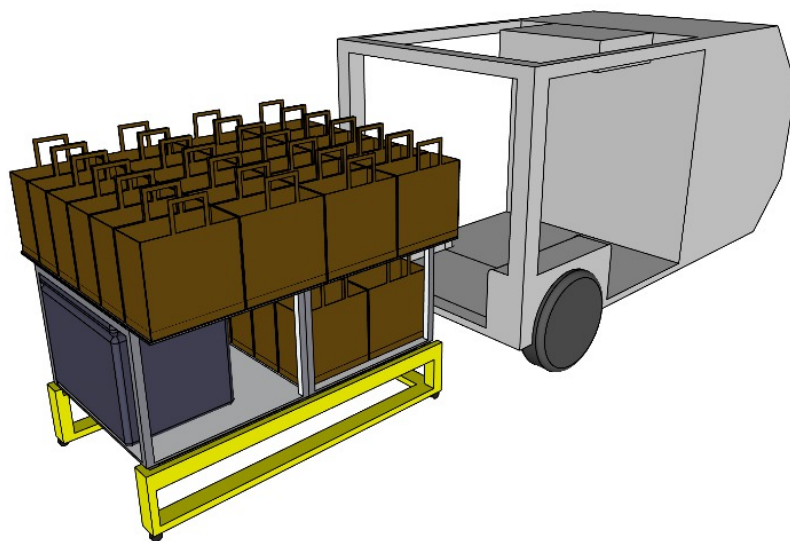


Concept comparison matrix  
(weighted)



## Resulting Concept

(Starting point for the next ideation phase)



**Figure 4.38:** Resulting concept based on feedback from Clean Motion and a concept comparison matrix.



# 5

## Procedures and Results: Second Iteration

This chapter describes the second iteration part of the project. Just as in the first ideation, it contains a research, ideation and evaluation phase.

### 5.1 Research Phase 2

In this second research phase areas investigated were a continued understanding of the market, the intended use case for the solution developed as well as freezer alternatives to be implemented. The goal of this phase was to further understand the needs of potential customers within the quick commerce industry as well as identifying, comparing and choosing one out of the suitable freezer solutions available.

#### 5.1.1 Continued Understanding of the Market Segment of Companies Operating Within Last Mile Delivery of Groceries

Further investigation was carried out after the first iteration, see Chapter 4, to continue to gain a deeper understanding of the needs of potential customers. One major consequence of the studies was a changed perception of the amount of bags a single order is estimated to contain, based on the further understanding of the potential market segment and development of what a suitable use case could be seen as. The amount was changed from six bags (a number based on conclusions from the affinity diagram in section 4.1.7.1) to between three and four bags.

##### 5.1.1.1 First Interview with an Operations Manager at Picsmart

**Procedure:** A semi-structured interview using an online video conferencing tool was carried out with an operations manager at the company Picsmart with the purpose to gain insight into how they handle last mile deliveries. Another aim was to evaluate the concept A, B and C from Ideation Phase 1, see section 4.2.8.

**Results:** Picsmart is a company active within the industry of last mile deliveries of groceries from grocery stores to an end customer. Operations were said to currently be focused on Stockholm. An insight into the operation of Picsmart given by the company representative was that Picsmart has different employees stationed inside

partnered grocery stores for packing the orders and other employees for loading and driving the vehicle during delivery.

The feedback on Concept A, Concept B and Concept C can be viewed in Evaluation Phase 1, see section 4.3.3. It was said that Picsmart generally never goes over 10 deliveries and that stacked orders can take 45 minutes or more to deliver. Single deliveries could take up to 12 minutes from the store to the customer. These operations could be seen to cover both quick commerce and planned deliveries. To separate and identify the orders the bags are marked with a felt-tip pen, and for each order they averaged 0.6 insulated paper bags and 3.6 paper bags. Thought on their current delivery vehicle Inzile were not that great, and can be read in detail in Appendix A, section A.6.

### 5.1.1.2 Second Interview with Picsmart

**Procedure:** A semi-structured interview using an online video conferencing tool was held with Picsmart's product and assortment manager, operations manager, and three people that had experience working as couriers within the company. One part of the aim of the interview was to gain feedback from Picsmart on a more developed concept. Another part of the aim was to gain a more thorough understanding of the needs and use situations where any interaction is made with the delivery vehicle, and to discuss any general problems the couriers face in their daily operation.

**Results:** For thoughts and feedback on the developed concept, see section 5.3.1. It was once again mentioned that the average delivery is 3.6 paper bags. It was added that 6 bags was the maximum a courier had been heard to carry at once.

A worry raised by the company representatives from Picsmart was that the cargo space of the delivery vehicle can be open for long periods of time if the courier has a hard time to identify the correct order. One person part of the conversation, with courier experience, believed that he could open up the cargo space, identify the correct bags and close the doors in about 10 seconds while trying to be quick. In some situations it was said to be challenging for the couriers to collect the paper bags from the plastic boxes that they were housed in. Especially when the weather was bad and they did not want to place the box or the bags on the ground.

The cargo space of their current vehicle could be opened from both sides and the back. Due to the size of the vehicle and doors that open upwards, orders were generally always accessed only from the back and the right side of the vehicle. The main reasoning for this was said to be in order to avoid standing in an unsafe place close to a trafficked road during unloading.

### 5.1.2 Storing Frozen Goods During Delivery

In this section, alternatives for storing frozen goods during delivery at a satisfactory temperature were investigated in order to choose one to implement. Research into

both active and passive freezer solutions were made in order to support this.

Through performed customer studies it was identified that there is a need for a freezer space part of deliveries, since a standard order typically includes some kind of frozen product, see section 4.1.7.1. The share of each order being frozen products was found to vary, but was estimated to be 10% or 5–6 liters. This was further confirmed in dialogue with a relevant actor within the industry of last mile delivery of groceries, see section 5.1.1.1. Here the average share of frozen products was said to be 60% of a bag of 11 liters, resulting in an average of 6.6 liters frozen goods per order. This is used as part of the background for the further investigation made into the choice of freezer solution.

### 5.1.2.1 Dometic ColdMachine VD-16 (when used with ColdMachine CU-96)

**Procedure:** Research was made into a product information sheet for technical specifications of the cooling unit ColdMachine VD-16, implemented as part of an active cooling system.

**Results:** Dometic ColdMachine VD-16 is an evaporator unit suitable for freezer temperatures, part of an active cooling system, see 2.3.4.2. VD-16 has the dimensions 330x260x130 mm, weigh 2.5 kg and has a cooling volume of 200 liters as the maximum capacity when used together with the compressor unit ColdMachine CU-96, part of the 90 series (Dometic Group, 2021b).

### 5.1.2.2 Freezer Alternative: Active Freezer

**Procedure:** Two lists with positive and negative aspects regarding the alternative of implementing an active freezer solution were created. The cooling system addressed as the active freezer alternative was set to utilize ColdMachine units, see section 2.3.4.2. These lists were based on insights into the freezer solution in relation to available alternatives in the form of passive freezer solutions as well as the intended use case and previous evaluation made, see section 4.3.5. The aim was to decide if it would be beneficial to implement an active freezer solution.

**Results:** The two following lists were compiled of positive and negative aspects of implementing an active freezer solution.

#### *Positives with an active freezer*

- + No additional handling of cold bearing medium.
- + Can have a larger cooling capacity, measured in volume.
- + Modest additional power consumption.
- + Can guarantee a low temperature during longer periods of time.

#### *Negatives with an active freezer*

- Puts an additional strain on the battery.
- Adds complexity of production.
- Not removable.

- Not flexible when it comes to adjusting the freezer volume.
- Cooling unit not being as space efficient as other alternatives.
- Requires an additional cooling system installed, separated from the cooling system of the refrigerated space.

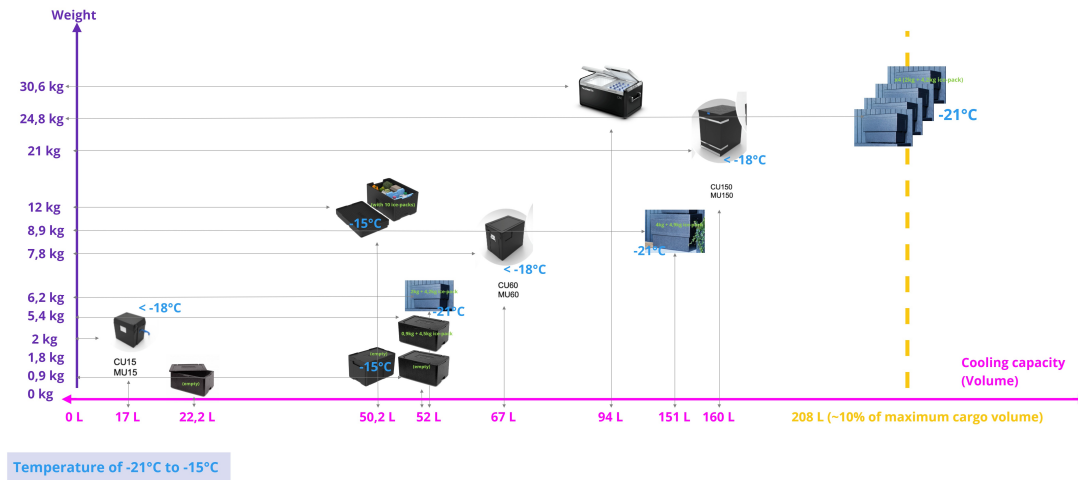
**Results:** The lists of positive and negative aspects of an active freezer solution showed that an active freezer posed more negative aspects than positive ones. The negative aspects were also seen as more relevant to take into consideration, related to for example the result of Elimination Phase 1, see section 4.3.5. This resulted in the elimination of the alternative of implementing an active cooling system for the freezer space.

### 5.1.2.3 Passive PCM

**Procedure:** Passive PCM, see section 2.3.3.1 was identified as one alternative to create a freezer space utilizing a passive cooling solution. Additional research was also conducted to see if PCM could be used for freezing temperatures, in addition to refrigerated temperatures. This was carried out online with the focus on investigating the current offering of products on the market. The ratio between the total weight of the cooling solution and the cooling capacity in volume was identified as relevant to consider, resulting in the creation of a graph comparing investigated products on these two aspects.

**Results:** Through research into the current offering of insulated boxes utilizing passive PCM blocks for cooling, an overview was made, see Figure 5.1. The providers of these products were seen as relevant actors within the market of passive PCM, being Polibox, iFoodbag and Vakava Technologies (Polibox, n.d.; iFoodbag), n.d.; Vakava Technologies, 2022).

The alternative of utilizing a battery driven electric cooler, such as products from the Dometic CFX series was also included in this comparison of weight to cooling capacity ratio through including the CFX3 95DZ cooler (Dometic Group, n.d.-a).



**Figure 5.1:** Overview of the market study of insulated boxes utilizing passive PCM for cooling, freezer temperatures, from Polibox (n.d.); iFoodbag) (n.d.); Dometic Group (n.d.-a); Vakava Technologies (2022).

Some conclusions were drawn from this weight to cooling capacity comparison. Mainly that the identified capacity need for a freezer space in volume could be seen to be fulfilled by utilizing several smaller PCM products. The dimension is seen as another area important to take into consideration, in relation to the paper bags identified as the standard packaging method. No elimination was made on the basis of dimensions at this stage, but it was noted that many of the insulated boxes part of this freezer solution had a lower height relative to the bottom area. It was also noted that many insulated boxes required additional paneling in order to be stable enough to use as a stand alone unit (Polibox, n.d.).

#### 5.1.2.4 Interview with Company Representative from iFoodbag

**Procedure:** A semi-structured interview conducted using an online video conferencing tool with a company representative at iFoodbag, that had lengthy experience of working with logistics and operations within the food and beverage industry. The aim for this interview was to gain an understanding of the offering of iFoodbag as a company that provides insulated packaging solutions for delivery of cooled groceries. Mainly intended for last mile delivery keeping an intact cold chain. The focus was put on the transport of frozen products. Afterwards, a follow-up interview was held to discuss if changes could be made to the product called alvobox offered by iFoodbag.

**Results:** The two types of products iFoodbag offers were presented: an insulated paper bag called the ifoodbag and an insulated box made out of expanded polypropylene (EPP) called the alvobox. Both of the products could achieve freezing temperatures, where the bags could be used in combination with freezable gel packs, and the alvobox with a freezable PCM block. Some differences were raised and discussed. One being that the alvobox was said to be able to keep a low temperature for a

longer time duration than the ifoodbag. In addition, the alvobox was introduced as a reusable form of packaging while the ifoodbag was generally seen as a single use packaging product. More information of the bag, the box, and food safety regulations can be seen in Appendix A, section A.7.

The use case of transporting frozen products for up to 2–3 hours within Re:Volt was considered realistic and suitable for the implementation of iFoodbag products as part of the freezer solution. Some emphasis was put by the interviewee on what a large difference it makes that the frozen compartment will be stored in an already cooled space, instead of in for example a hot car on a summer day where the temperature in the cargo space can be very high.

### 5.1.2.5 Dry-ice

**Procedure:** Research was made into the freezer solution of utilizing dry-ice in combination with some insulated box.

**Results:** It has been found in the investigation of the targeted market that several actors active within the industry of larger, planned deliveries of groceries currently utilize dry-ice in insulated boxes in order to create freezer temperatures, see section 4.1.7.1.

For the resulting insights into the use of dry-ice as a cold bearing medium for a freezer solution, see section 2.3.3.3. Dry-ice is seen as a passive cooling solution, but unlike other passive cooling alternatives such as PCM blocks it can not be reused. Dry-ice is said to have to be bought from a producer of dry-ice with the intention to use within two days of the purchase (Gases, n.d.). Another area covered in the theory of dry-ice, see section 2.3.3.3, were the high needs for ventilation and separating the cargo space from the driver cabin in order to not pose any danger to the driver during transport and unloading of goods. A second way dry-ice was found to be seen as potential hazardous was in relation to the employee's handling of the cooling media, based on the low temperature. In the case of manual handling of dry-ice, this is mostly regarding hand protection in the form of gloves when being in direct contact with the dry-ice (Praxair, 2016). Due to these factors, dry-ice was seen as unsuitable.

### 5.1.2.6 Freezer Alternative: Passive Freezer

**Procedure:** The cooling systems addressed as the passive freezer alternatives were set to utilize PCM blocks or dry-ice in combination with insulated boxes. The aim was to decide what passive freezer solution would be most suitable to implement.

**Results:** Both passive freezer alternatives of PCM blocks and dry-ice were deemed to satisfy the capacity needed for a freezer space if used in combination with four insulated boxes of around 50 liters each. The freezer alternative to utilize dry-ice

was eliminated on several points. These were related to time limitations regarding the cooling capacity, limited gain in having a lower weight relative to the cooling capacity than PCM blocks as well as a need for continuous external supply of the cold bearing medium from a dry-ice producer, close in time to the intended use.

The product alvobox was chosen over other similar solutions of insulated boxes with a PCM block. This was based in the integrity of the product enabling use without needing any additional structural elements, the height of the box largely utilizing the available space between the lower and upper shelf in the shelf structure as well as access to a satisfactory level of data and information provided in order to validate the freezer capabilities when implemented. The total weight of utilizing the alvobox was also seen as reasonable and justifiable in relation to the volume capacity relative to similar solutions of insulated boxes in combination with PCM blocks. More comments regarding the alvobox can be read in Appendix B, section B.2.

### 5.1.3 Doors

The openings and thereby doors to the cargo space is an important area for both thermal energy loss as well as accessibility and the interaction with goods during loading and unloading.

#### 5.1.3.1 Insights from Development Engineer with Cooling Technology Expertise

**Procedure:** Interviews with a development engineer with cooling technology expertise, see section 4.1.6.2, were carried out in order to identify standard door solutions and important aspects to consider regarding doors to a cooled space. Areas covered were door-like solutions for openings in general, different types of doors for vehicles as well as doors used as part of a vehicle with a cooled cargo space.

**Results:** For some insights regarding doors to a cooled cargo space gained from the interview with a development engineer with cooling technology expertise, see section 4.1.6.2. One relevant point was that the door has to be fully insulated. This results in the limitation that the use of a metal roller shutter for a door can be seen as too complex to implement. Another point raised was that doors to a fully insulated, cooled cargo space should be seen as weak points. The sealing around doors was found to be important to consider in order to limit the increase in passive thermal energy loss related to doors to the cooled cargo space.

#### 5.1.3.2 Retention of Cold Air During Door Openings

**Procedure:** Direct contact with relevant people knowledgeable on thermodynamics, see section 4.1.6.1 was made, with one aim to gain insight into the impact of different parameters related to doors and openings.

**Results:** Some insights regarding the role of doors were gained through investigation of some of the potential causes for cold air to leave the cargo space when a door is opened, see section 4.1.6.1. One factor in the cause of cold air loss was said to be related to the turbulence caused by a door opening. It was assumed that a decrease of the size of the door opening would decrease the cold air loss caused by this turbulence to some extent.

### 5.1.3.3 Online Research and Observations of Different Door Variations

**Procedure:** Research online as well as insights from observations, see section 4.1.4 was made of different door types. This covered different designs of doors in general, different door variations on vehicles as well as door variations seen to be part of a vehicle with a cooled cargo space.

**Results:** The research into available types of doors resulted in three categories of doors. One being different variations of doors at large, one being different door variations part of vehicles in general and one being doors part of vehicles with a cooled cargo space.

Normal doors can be seen in Figure 5.2, different doors to vehicles in in Figure 5.3, and doors to a cooled cargo space in Figure 5.4.



**Figure 5.2:** General doors.

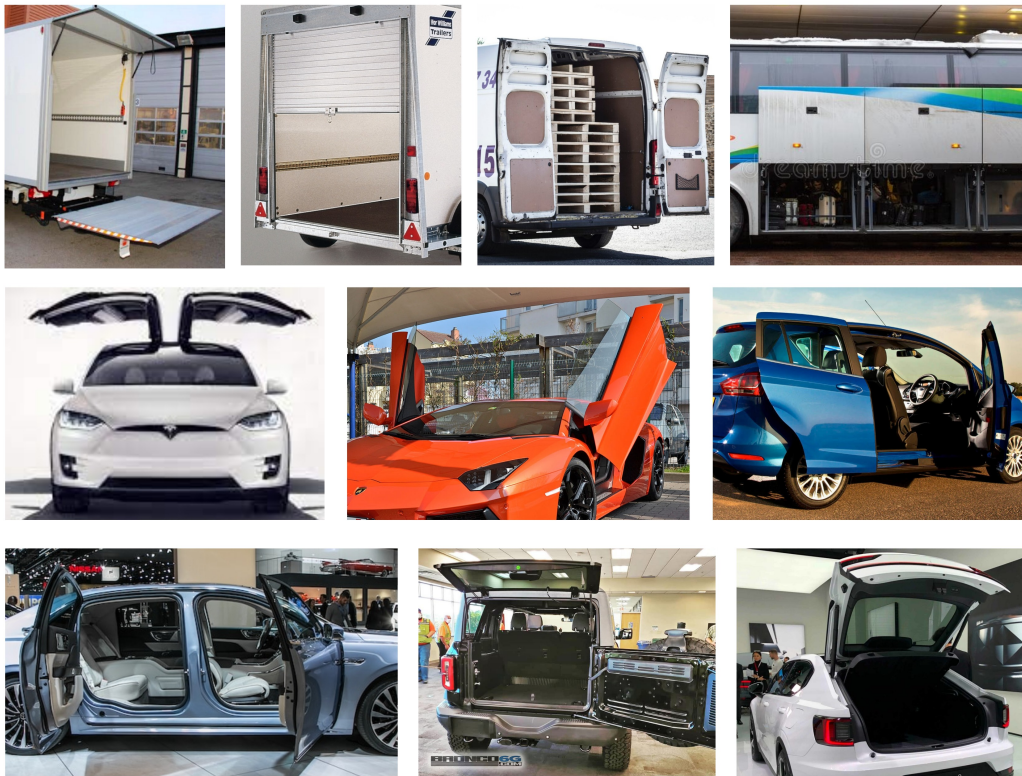


Figure 5.3: Different doors to vehicles.



Figure 5.4: Different doors to a cooled cargo space.

It has been found from this online research as well as performed observations, see section 4.1.5, that there is a clear standard for the type of doors used as part of the cargo space in vehicles with a cooled cargo space. This type of door was fully insulated, horizontally opened with the hinges on one of the vertical edges and had a rubber seal that surrounded all edges. This type of standard door was chosen for implementation in the final concept.

## 5.2 Ideation Phase 2

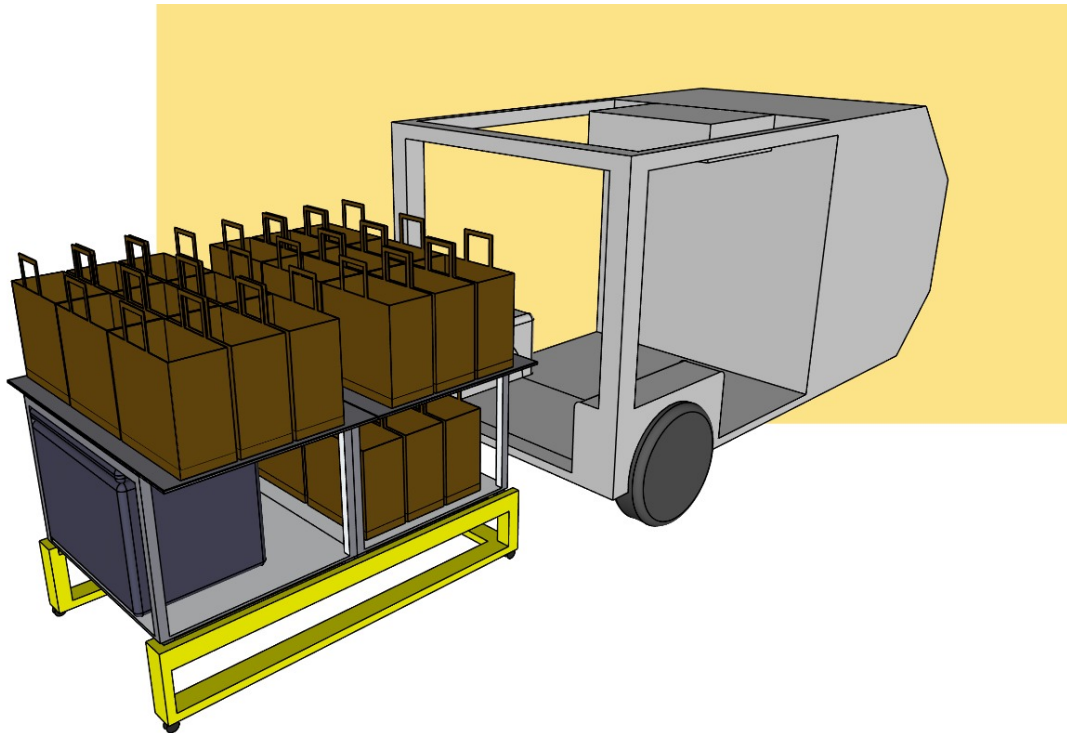
The focus during this phase was mostly regarding smaller details for the final solution, being:

- Organization and structure of orders.
- Offering direct access to orders.
- Physical limitation of active thermal energy loss.
- Handles and other interactions points for the shelf unit modules.
- Implementation of the chosen freezer solution.

An added aim was to create a solution that should be functional with everything included in the solution from the start. Solidifying the aim of developing a concept for a final product, increasing the flexibility in possible operations where the solution could be implemented.

### 5.2.1 Starting Point for Ideation Phase 2

Insights from the first evaluation phase, see section 4.3.5 were combined into a concept acting as the starting point for the second ideation phase. The starting point for Ideation Phase 2 was one movable shelf unit placed on a transportation dolly when removed from the cargo space, see Figure 5.5. The freezer box was seen as removable and placed at the lower shelf, at the back of the shelf unit.

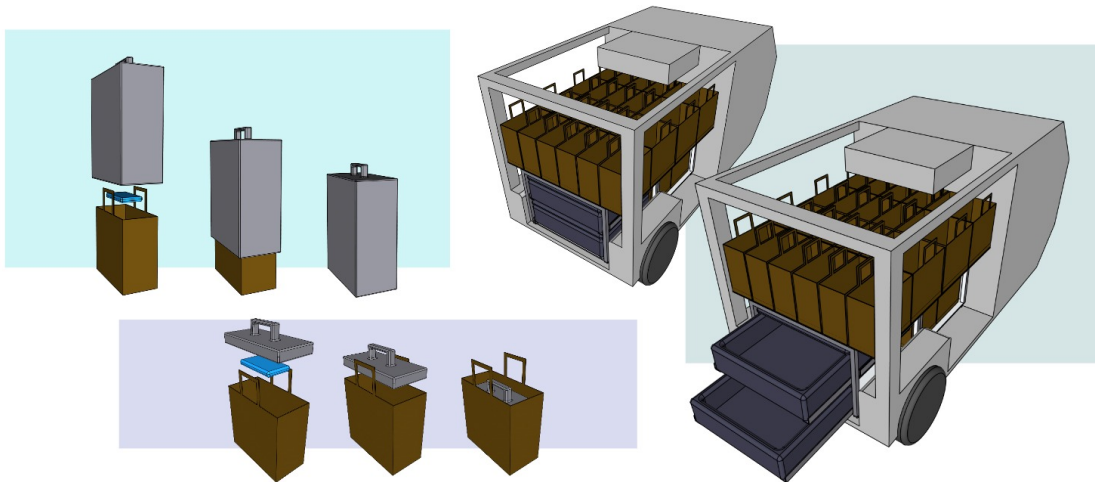


**Figure 5.5:** The concept acting as a starting point for Ideation Phase 2.

## 5.2.2 Offering of a Freezer Space

**Procedure:** Discussions supported by sketching and CAD were used to create several concepts for offering a solution for transport of frozen goods. In addition, existing solutions were researched online. The feasibility of different solutions were analyzed in one way by visualising them in CAD. The solution decided to be further investigated was used in a test conducted with a 1:1 scale mock-up of Re:Volt.

**Results:** Figure 5.6 illustrates two solutions that could enable freezing for individual bags, and one solution that would utilize drawer-type freezer boxes. The first two solutions would enable any bag to house frozen goods, but would also result in many physical objects that would have to be stored somewhere. The drawer-type freezer would not be able to house paper bags of any typical dimensions, due to their shallowness. All three solutions would also have to be produced and developed, which is why these concepts were eliminated.



**Figure 5.6:** Exploration of different concepts for offering a freezer solution.

Another insulated box that could be used as a drawer type freezer is a product called alvobox, see figure 5.7.



**Figure 5.7:** Photos of the large and small alvobox offered by iFoodbag.

It was decided to further investigate the potential implementation of both the smaller alvobox of 51 liters and the larger alvobox of 151 liters, see section 5.1.2.6. The decision of what version of the alvobox to implement was supported by testing both versions in combination with a 1:1 scale mock-up of Re:Volt, see section 5.2.3.

### 5.2.3 Interaction with Physical Large Scale Mock-up

A full scale (1:1) mock-up of Re:Volt was created as a continuation of the existing full scale mock-up of the cargo space of Re:Volt, see section 4.2.5. The simple structure representing the cargo space made of wooden studs and 3D printed corners were placed on top of an already existing structure created by the people at Clean Motion, see Figure 5.8.



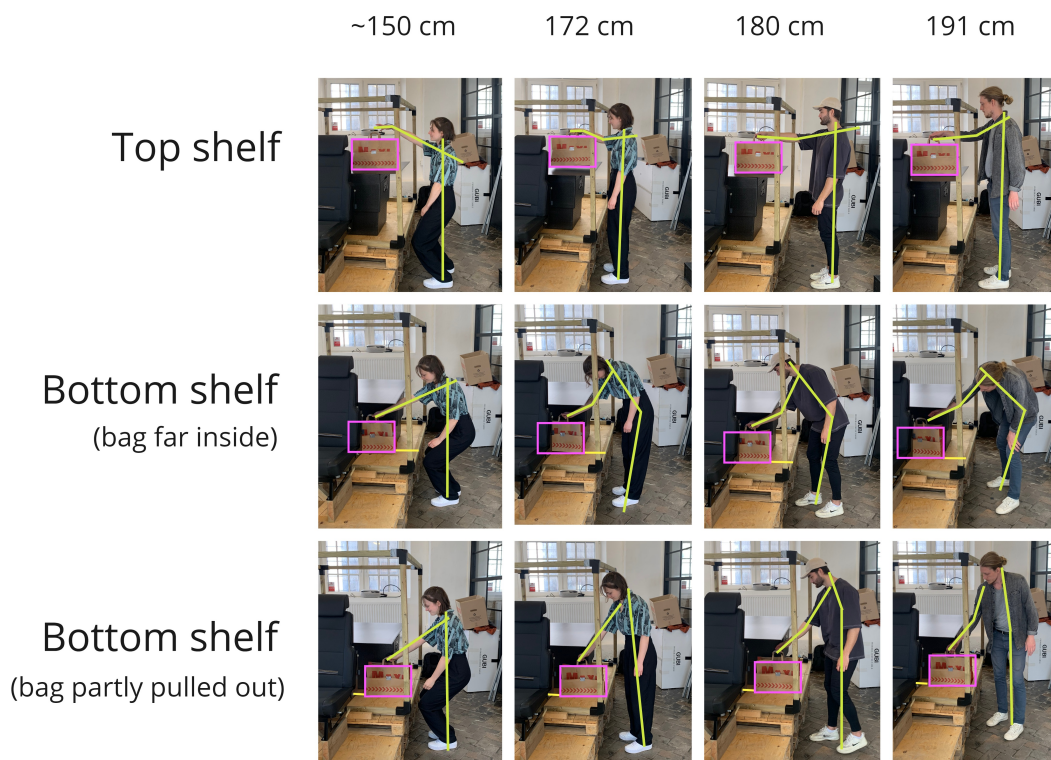
**Figure 5.8:** 1:1 scale mock-up of Re:Volt.

### 5.2.3.1 Unloading of a Paper Bag from the Upper and Lower Shelf

**Procedure:** To the 1:1 scale mock-up of Re:Volt a simple structure representing the shelf structure concept acting as the starting point for the second ideation phase was added. The upper shelf was represented using a plastic sheet, mainly to set the right height since that was considered the main aspect affecting the interaction with the shelf. Cardboard was used to construct a representation of one of the two wheel houses. An empty paper bag was used in the interaction with the mock-up.

The smaller tasks of unloading goods in the form of a paper bag from the side of the cargo space was carried out using the mock-up. This was done by three different people, representing four heights where the lowest height was an estimate by bending in the knees. The heights were about 150 cm, 172 cm, 180 cm and 191 cm. These heights were seen to be representative for the user group identified and can be seen as represented by the personas, see section 4.1.5.6.

**Results:** The interaction with the mock-up resulted in some take-aways related to the influence the height of the user can be seen to have on the lifting position of bags, see Figure 5.9.



**Figure 5.9:** Illustrations of how people of different height (about 150 cm, 172 cm, 180 cm and 191 cm) handle different situations of lifting a paper bag during unloading.

It was found to be more beneficial for the shoulder position to be 180 cm tall than being 172 cm when lifting bags off the upper shelf. If being even shorter, the person’s shoulder might be forced to be in a more extreme position with the hand over their shoulder height when lifting the bag. This would motivate that an available platform to step up on beside the vehicle would support some people when loading and unloading bags where reach or height pose a challenge.

It was identified that it can be difficult for taller users, here tested as 180 cm and 191 cm tall to reach the bags on the lower shelf when the bags are far inside of the vehicle. It was seen to result in a more beneficial position when the bags were placed at the edge of the shelf when initiating the lift.

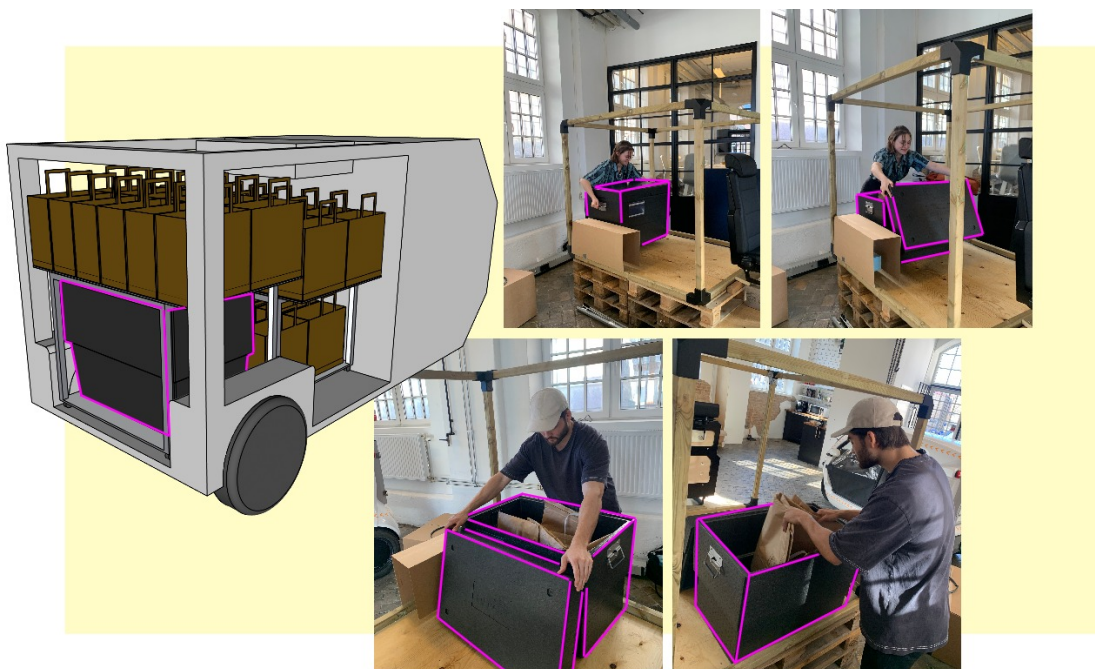
### 5.2.3.2 Accessing the Content of the Freezer Solution, Two Versions of an alvobox

**Procedure:** One larger alvobox of 151 liters and one smaller alvobox of 51 liters was provided by iFoodbag. These two insulated boxes were tested together with the 1:1 scale mock-up of Re:Volt, carrying out the tasks of opening, accessing contents and closing the insulated box. For the test the box was placed to be accessed from the

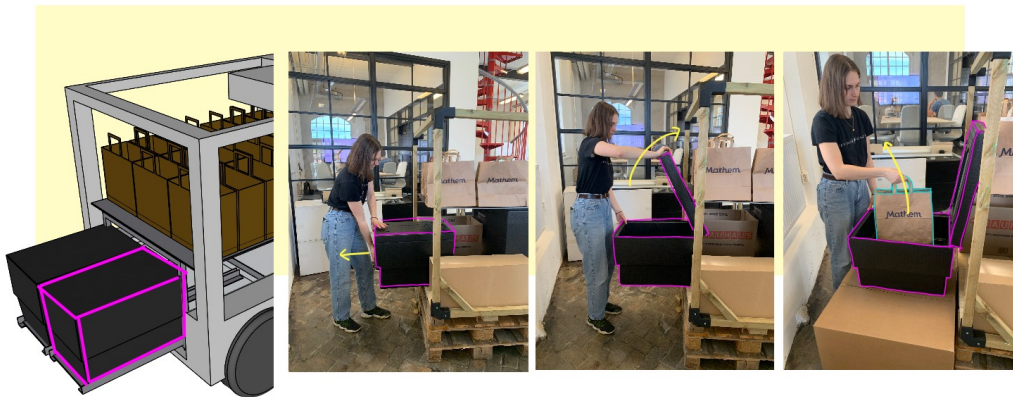
back of Re:Volt, place in between the wheels on the lower shelf of the shelf structure.

**Results:** Figure 5.10 illustrates a CAD visualisation as well as some situations observed as part of the test in practice using the full scale mock-up of Re:Volt with the large alvobox. The test showed that the larger box was hard to manage due to its size. Therefore, the smaller alvobox was also tested. It was illustrated using a CAD visualisation as well as incorporated in a test using the full scale mock-up of Re:Volt, see Figure 5.11). It turned out that the smaller sized alvobox was much more manageable and therefore preferred over the larger sized one.

The mock-up test of accessing the contents of the freezer box in the form of a larger and smaller alvobox also gave insights regarding what kind of additional structure such as handles and fastening points would be beneficial. It was found as important that the freezer box can be opened, accessed and closed using one hand. In practice, this resulted in pulling out the box, using the inner short edge as a hinge and using the upper shelf as a rest to keep the lid open while accessing the bags inside the freezer. Since the PCM block placed inside of the lid inside the small alvobox weigh about five kg whilst the box itself weigh about one kg, the box was also found to be very top heavy. This was thus another aspect seen as relevant to address, in order to prevent the box from tipping during handling.



**Figure 5.10:** Usability testing with a large alvobox from iFoodbag.

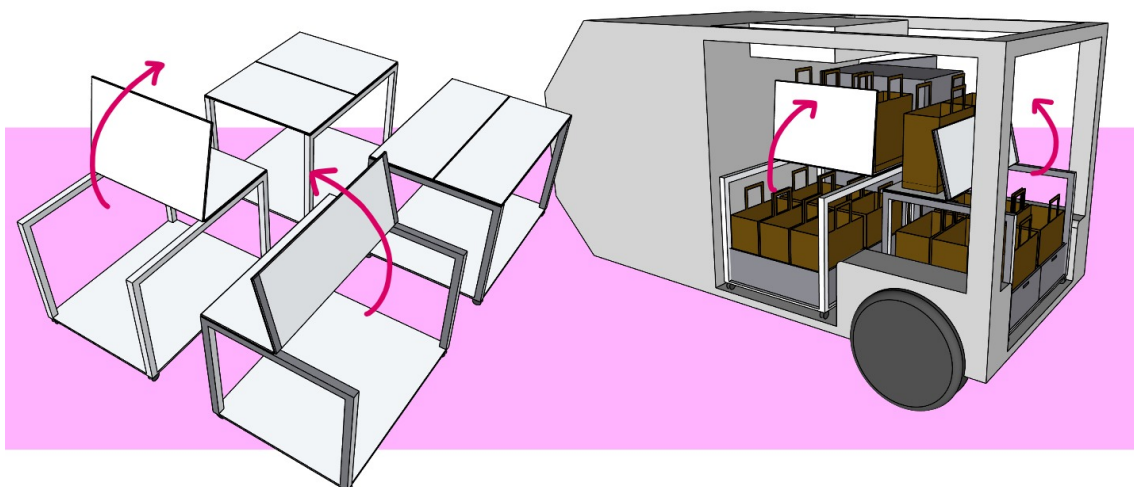


**Figure 5.11:** Usability testing with a small alvobox from iFoodbag.

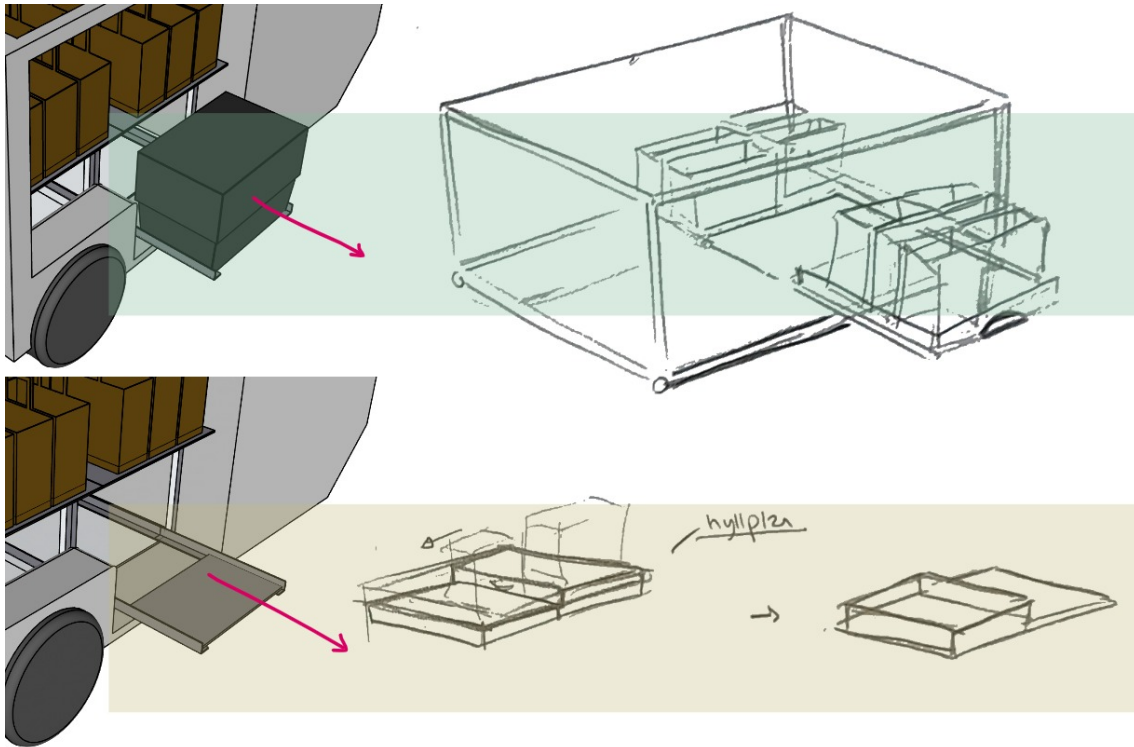
### 5.2.4 Direct Access to Paper Bags

**Procedure:** Ideas for enabling more easy access to paper bags placed on the lower shelf inside of Re:Volt was investigated using sketching and CAD software, with the aim to create some concepts for this specific area to be implemented in the larger concept.

**Results:** Two concepts were created to support the user in accessing goods such as paper bags placed on the lower shelf of the shelf structure, see Figure 5.12 and Figure 5.13.



**Figure 5.12:** CAD visualising a shelf structure where the upper shelf is foldable.



**Figure 5.13:** Sketches in combination with CAD showing a pull-out shelf systems part of the lower shelf carrying a freezer box or paper bags.

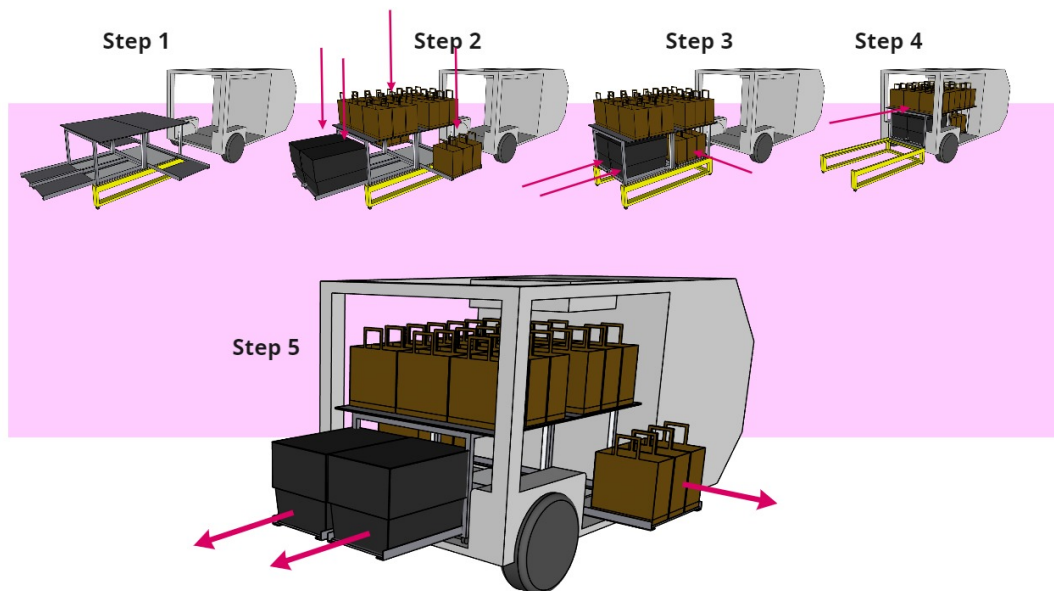
Figure 5.12 illustrates shelves that can fold up, which is considered to create a more ergonomic lifting situation for a person that is about to lift bags out of the lower shelf. This is put in comparison to a non-foldable shelf, as seen in 'bottom shelf, bag far inside' situation in Figure 5.9, see section 5.2.3.1. However, the solution is dependant on the upper shelf being fully empty in order to function well.

Another solution considered was a pull-out bottom shelf system, see Figure 5.13. The solution would not be dependent on an empty upper shelf and would also enable a top loaded freezer box to be placed on the pull-out shelf. This box was seen to be possible to open by tilting its lid up, or removing the lid completely. Based in these conclusions, the pull-out bottom shelf solution was deemed superior to the fold-up shelf solution. An aspect seen as relevant to consider when moving forward with the concept of pull-out bottom shelves was the need for a strong, lightweight sliding mechanism implemented as part of the pull-out shelf. The implementation of something like a pull-out bottom shelf as a way to offer more easy access to the lower shelf could be seen to be supported by the results of the physical tests performed using the full scale mock-up of the cargo space of Re:Volt. This mock-up was used together with a structure representing the height and positioning of the shelf structure concept, together with a paper bag similar in size to the paper bag set as standard. The people included represented the heights of about 150 cm, 172 cm, 180 cm and 191 cm. The results being that it was more challenging for all test people to reach a paper bag positioned further towards the center line of the cargo space compared to reaching a bag placed further out, at the edge of the cargo space.

### 5.2.5 Mid-Concept Ideation Phase 2

**Procedure:** CAD was used to combine insights from Evaluation Phase 1, Research Phase 2 and Ideation Phase 2 up until the mid-point of that phase. The starting point for this concept was a continuation of the concept acting as a starting point for Ideation Phase 2, see section 5.2.1.

**Results:** The result can be seen in figure 5.14 and was a concept that consisted of a movable shelf unit with four pull-out bottom shelves, utilizing a transportation dolly when being removed from the cargo space. The bottom shelves could store a range from zero to four alvoboxes of 52 liters each, which made the concept flexible when it came to the amount of frozen goods it would need to house at a specific time. Depending on the need for a freezer space, these lower shelves could also be used to house three additional paper bags per shelf.



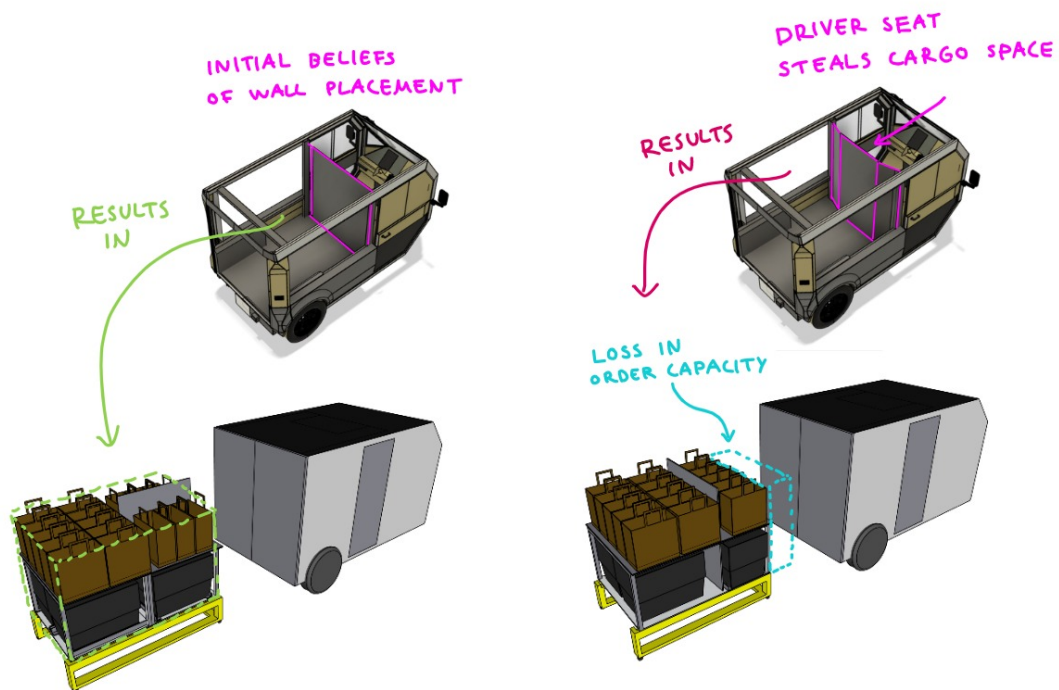
**Figure 5.14:** Mid-phase concept, consisting of a movable shelf unit with four pull-out bottom shelves.

### 5.2.6 Internal Walls' Positioning and the Effect on Order Capacity

**Procedure:** The right hand side in Figure 5.15 illustrates a structural change in positioning of one of Re:Volt's transverse inner walls at the front of the cargo space, that had been unknown up to that point in the project. The positional change of the inner wall was discussed with the CEO of Clean Motion, where the goal was to solve this issue.

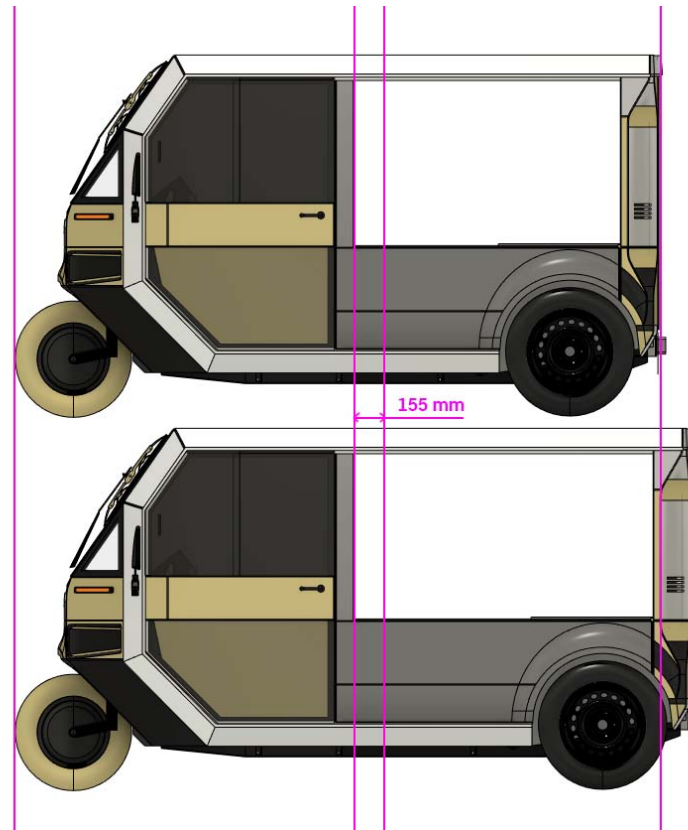
**Results:** The change of the wall positioning was based in the finding that the drivers seat would have to be pushed back to give sufficient space between the

driver and the brake pedal, which consequently would push the wall behind it being the front wall of the cargo space backwards into the cargo space. This change would result in a decrease of the cargo space, which would mean that the current concept would have to be changed in accordance to Figure 5.15, thus leading to a substantial decrease in order capacity.



**Figure 5.15:** Difference in capacity from small and large concept.

The discussion with the CEO of Clean Motion resulted in insights regarding the difficulty in changing dimensions of the vehicle Re:Volt. Out of the height, width and length of the vehicle, the length was the parameter said to be the easiest to adjust from a production perspective. A compromise that meant that the vehicle would have to be elongated at least 15,5 cm in the area between the front wall of the cargo space and in front of the wheel houses, see Figure 5.16 in order to house the concept developed. The elongation would result in both sufficient space for the driver and the current concept to fit in the cargo space.

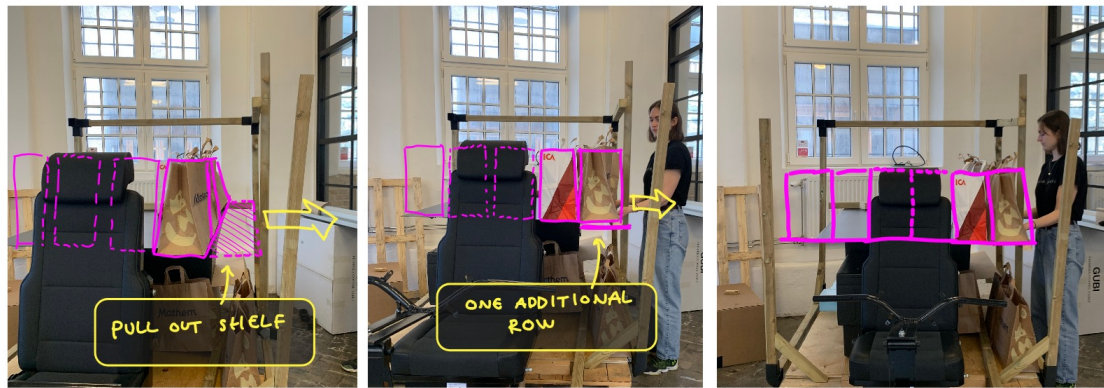


**Figure 5.16:** Visualisation of necessary elongation of Re:Volt.

### 5.2.7 Revisiting Extendable Shelves

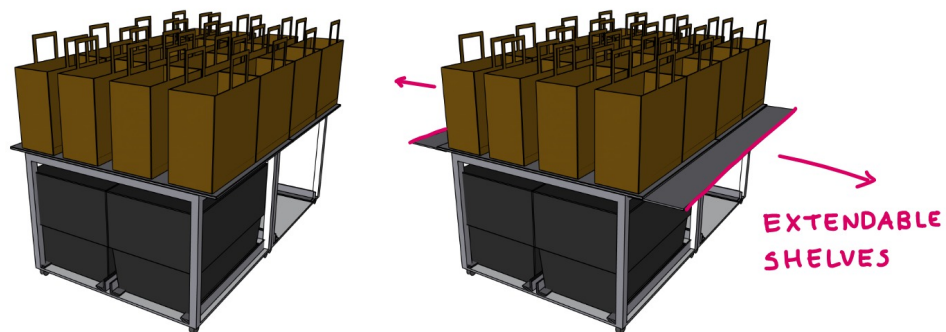
**Procedure:** A new realization regarding the foldable shelves in an earlier concept in Ideation Phase 1 called Concept B, see section 4.2.8.2, along with new measurements of Re:Volt’s cargo space, sparked a new discussion.

**Results:** The discussion resulted in a test with the full scale, physical mock-up. An extendable upper shelf was represented by holding a piece of wood outside of the intended base of the upper shelf to then place additional paper bags on, see Figure 5.17).



**Figure 5.17:** Usability testing of an extendable upper shelf.

The option of having horizontally extendable shelves seemed to be a more feasible option than the previous fold out shelves that were implemented in Concept B in Ideation Phase 1, see section 4.2.8.2. The main reasons being how the extendable shelves could enable more bags to be stored, without interfering with the base part of the upper shelf. Thus, a concept CAD model for this was created, see Figure 5.18, and the solution was implemented in the final solution.



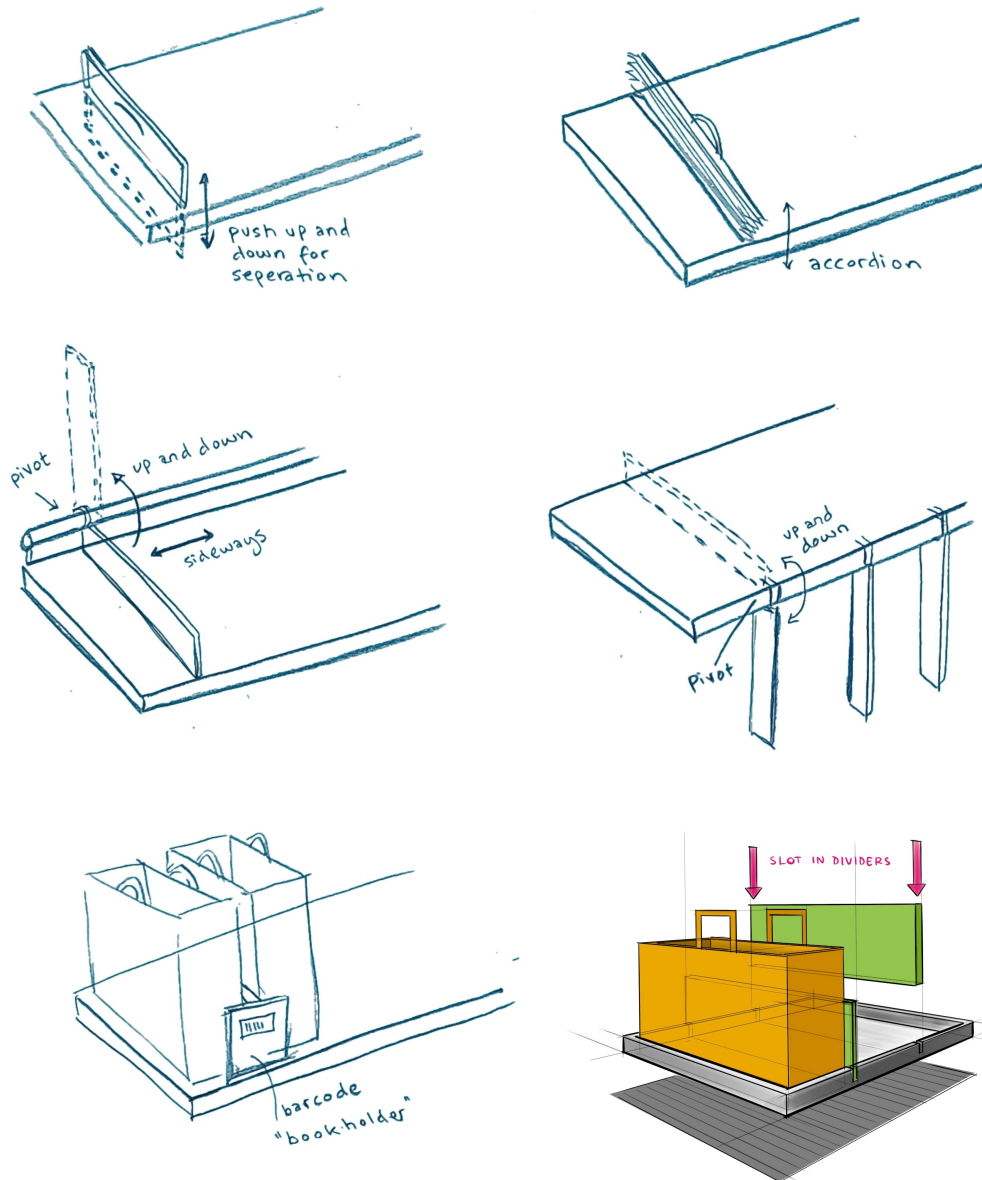
**Figure 5.18:** Extendable shelves part of the upper shelf in the shelf structure.

## 5.2.8 Separating and Securing Orders

**Procedure:** Sketches along with physical testing with paper bags and other additions to the full scale mock-up of Re:Volt was used to support the generation of ideas regarding the separation and organisation of orders. A goal for the ideation was to aid physical and cognitive ergonomics of the courier. Aspects identified to support this was by making it clear for the user where and how they should place their bags, how to group bags part of the same order and separate them from bags part of other orders along with the structure acting as a hinder for the bags from sliding around while driving.

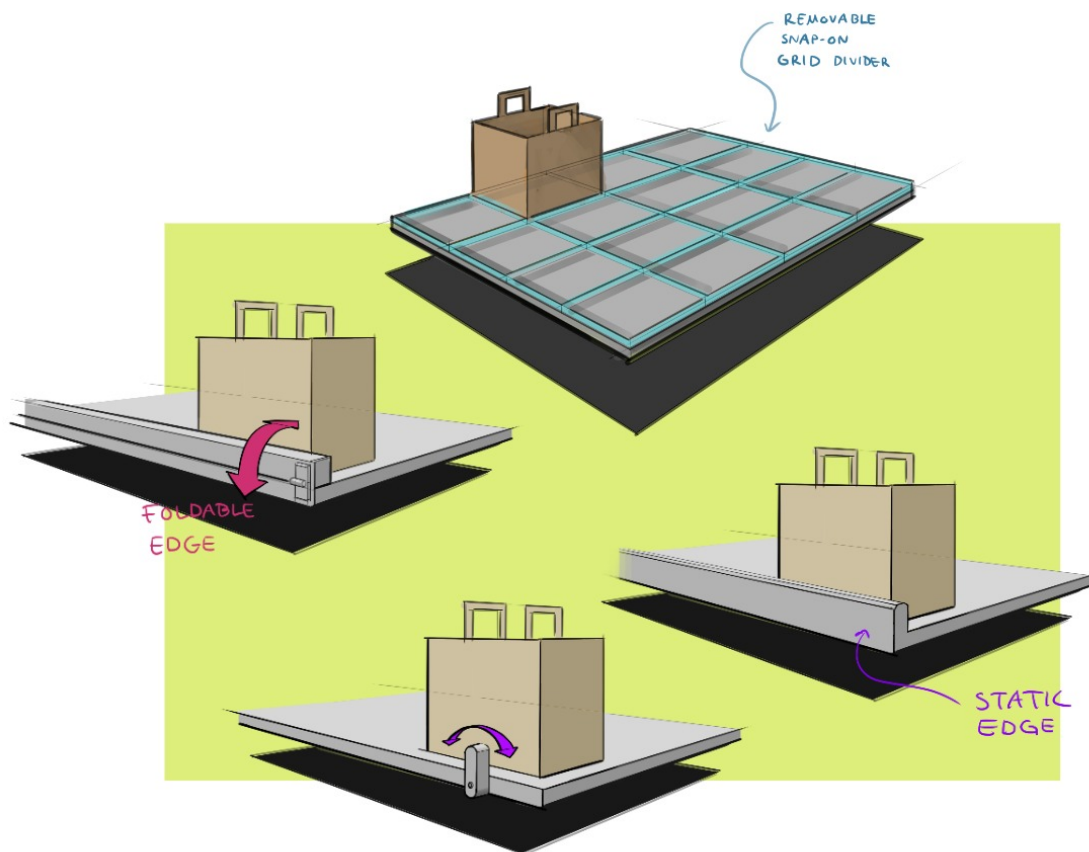
## 5. Procedures and Results: Second Iteration

**Results:** The results were sketches of six different ideas on how bags could be separated and segmented into orders, so that a courier more easily could identify the correct bags in a given order, see Figure 5.19.



**Figure 5.19:** Sketches for separation and segmentation of orders.

Other sketches, see Figure 5.20 illustrated four different ways identified to prevent bags from sliding around and falling of the edges of the shelf during loading, transport or unloading.



**Figure 5.20:** Sketches of different ways to prevent bags from sliding around during transport or to fall off the shelf during loading, transport or unloading.

It was determined that a single solution could fulfill the need for all aspects of separating, segmenting and preventing orders from moving or falling over during transport.

## 5.2.9 Organisation of Orders

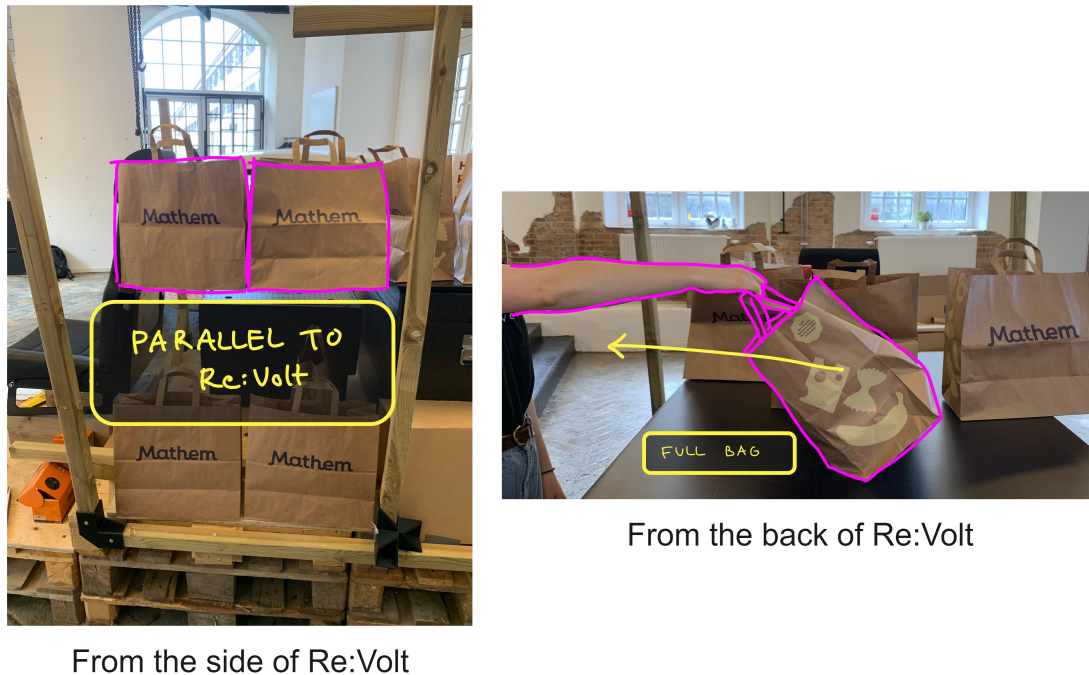
The organisation of orders, with a focus on the upper shelf was identified as important to consider and influence through the solution developed. It has a direct impact on the carrying capacity of the solution as well as both the physical and cognitive ergonomics of the courier in both a loading and unloading situation.

### 5.2.9.1 Physical Test of Direction of Paper Bags on Upper Shelf

**Procedure:** Physical tests using paper bags and a representation of the current shelf concept in combination with the full scale mock-up of Re:Volt was used to conceptualize how paper bags could be oriented and configured as part of the current concept with a focus on the upper shelf.

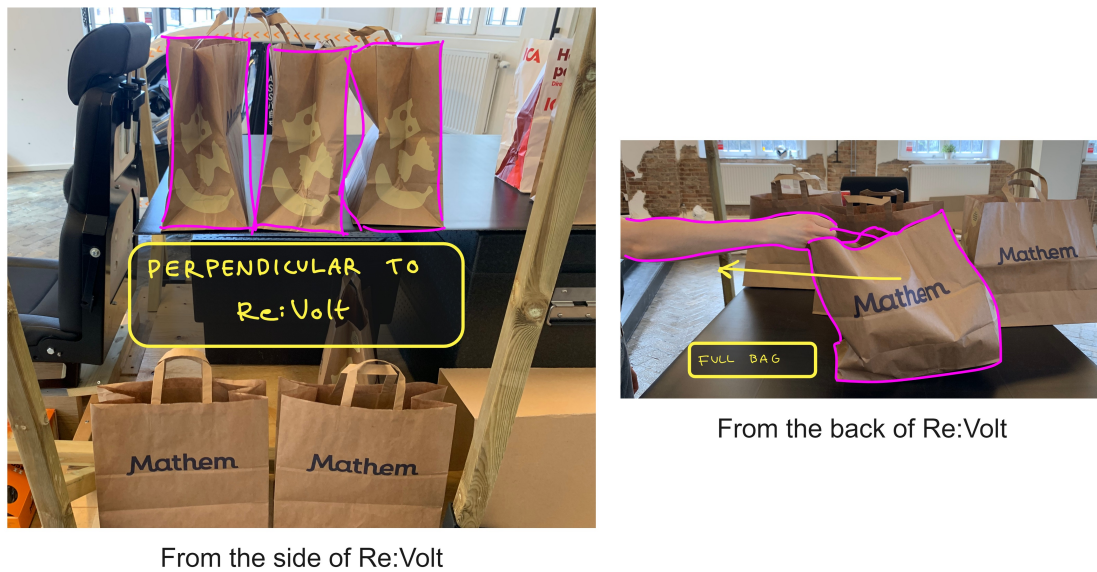
**Results:** The physical tests with the mock-up of the concept shelf structure and of Re:Volt resulted in the realization that it could be beneficial to place paper bags in

a direction parallel to Re:Volt's driving direction, see Figure 5.21.



**Figure 5.21:** Visualisations of tests of the lifting situation during unloading from the side of Re:Volt with paper bags placed on the upper shelf, parallel to the driving direction of Re:Volt.

This was, among other things, based in how heavily loaded bags acted while being pulled from the position of being placed perpendicular to the driving direction of Re:Volt, see Figure 5.22. When paper bags was placed perpendicular to the driving direction of Re:Volt, it was seen that bags could be more likely to get stuck in the shelf they were placed on when being unloaded, and therefore would have required an increased lifting motion by the user. Related to the added detail of enabling an extendable part of the upper shelf, see section 5.2.7, a parallel bag positioning was also seen to support the implementation of the kind of extendable shelves investigated.



**Figure 5.22:** Visualisations of tests of the lifting situation during unloading from the side of Re:Volt with paper bags placed on the upper shelf, perpendicular to the driving direction of Re:Volt.

### 5.2.9.2 Incorporation of a Middle Divider to Support Organisation of Orders and User Interaction Related to Shoulder Position

**Procedure:** As part of the physical tests using paper bags and a representation of the current shelf structure concept in combination with the full scale mock-up of Re:Volt, the number of rows of paper bags parallel to the driving direction of Re:Volt was tested and discussed in relation to the shoulder position of the user, with a focus on an unloading situation. The addition of a middle divider lengthwise to the cargo space was investigated.

**Results:** The standard bag used in concepts set to be 17 cm wide was empty when measured, see section 4.1.4.5. As part of the physical tests using the shelf structure concept in combination with the full scale mock-up of Re:Volt, a full paper bag of a similar size to this standard paper bag was implemented. This additional space was seen as desirable to have available per filled bag, to support the integrity and separation of bags. This was the main driver for solidifying the decision of organising paper bags on the upper shelf in four rows over five rows, see Figure 5.23.



**Figure 5.23:** Physical test of implementing four and five rows of paper bags on the upper shelf together with a full scale mock-up of Re:Volt and a representation of the shelf structure concept with similar dimensions.

Another factor investigated related to the number of rows of paper bags placed parallel to the driving direction of the vehicle was the distance required to cover to reach paper bags in different rows when unloading from the upper shelf. More specifically, how this distance was seen to influence the shoulder position of the user during the lift. It was identified in the physical test using test people of the heights 172 cm and 180 cm that the shoulder position can be seen as undesirable when reaching for a bag in the third row from the outer edge when the paper bag is placed in a parallel position, see Figure 5.24.



**Figure 5.24:** Physical test and overlaid sketches to visualise the impact of paper bag placement on shoulder position during unloading from the upper shelf, the test person being 180 cm tall.

A benefit identified with the bag positioning being parallel to Re:Volt's driving direction was that it would enable a natural way to integrate a divider lengthwise to the cargo space along the middle of the upper shelf, see Figure 5.25. The divider could in turn support the creation of sections on the upper shelf that could aid the organization and separation of orders.

This would be done by using a divider in the middle of the upper shelf lengthwise the cargo space, see Figure 5.25. This divider was also seen to limit the likeliness of the user putting themselves in an unfavourable lifting position. This was a potential behaviour identified as part of users similar to the persona Kim, see section 4.1.5.6, where the user might reach further into the cargo space instead of going around to the other side of the vehicle in order to save time even if it would result in a potentially harmful lifting position. This was mainly related to shoulder position during loading and unloading of a paper bag from the upper shelf, where the implementation of four rows over five and a divider in the middle would limit the amount of rows one has access to from each side of the cargo space. Resulting in the user not being able to unload paper bags being further away from them than maximum the middle of the cargo space from the side of the vehicle.



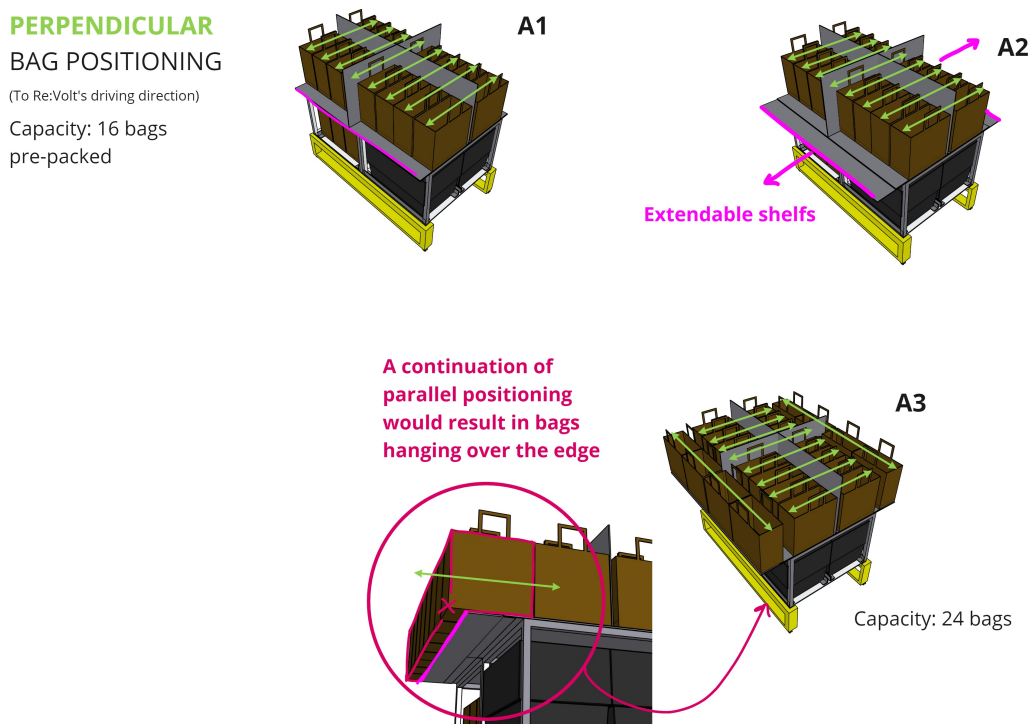
**Figure 5.25:** Physical test and overlaid sketches to visualise the implementation of a divider in the middle of the upper shelf, seen from the back of the cargo space.

### 5.2.9.3 Visualisation and Conceptualization of the Organisation of Paper Bags on the Upper Shelf

**Procedure:** CAD software were used in combination with overlaid sketches in order to visualize different configurations of paper bag placements on the upper shelf of the shelf structure. These configurations had previously been physically tested using a representation of the concept in combination with a full scale mock-up of Re:Volt, see section 5.2.9 and 5.2.8.

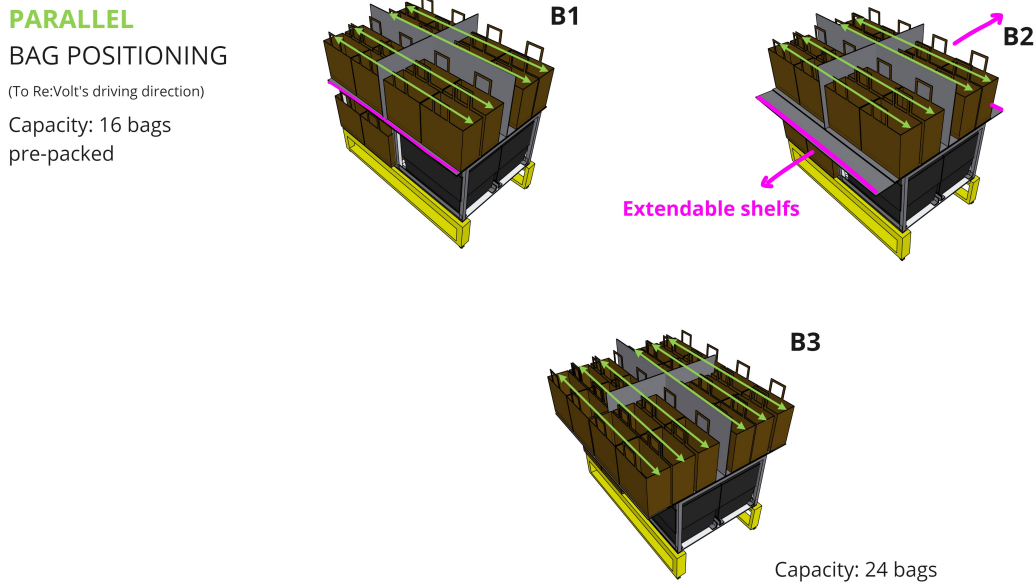
**Results:** Illustration A1 to A3 in Figure 5.26 visualize how paper bags would be

placed perpendicular to Re:Volt’s driving direction. The configuration would be able to house 16 bags in its standard configuration, and 24 bags if it had extendable shelves implemented as part of the upper shelf. However, the additional 8 bags would have to be placed in a parallel manner so they would not hang over the edges. The inconsistency in bag orientation could be seen to potentially pose an issue when it comes to cognitive ergonomics. This would mainly be due to an incongruency between a identified likely mental model of the user to position bags all in the same direction, and the actual set-up that require the person to place bags both parallel och perpendicularly orientated.



**Figure 5.26:** Visualization of how bags would be placed on the upper shelf of the concept if they were placed perpendicular to Re:Volt’s driving direction at the base upper shelf and placed parallel to the driving direction on the two extendable shelves.

On the contrary, illustration B1 to B3 in Figure 5.27 show bags placed parallel to Re:Volt’s driving direction. The bag orientation would result in the same amount of bags as in the other constellation, but it could be more congruent with a users mental model (of potentially positioning bags in the same direction) and the requirements of placing bags in a parallel manner. Thus, this second option was seen as beneficial and used in the continued concept development. A user test was previously made with the chosen bag positioning, see Figure 5.17 in section 5.2.7.

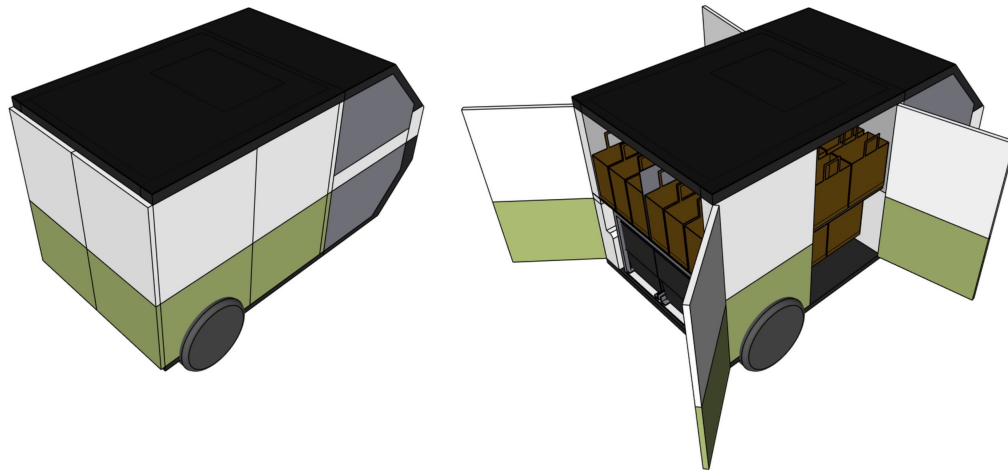


**Figure 5.27:** Visualization of how bags would be placed on the upper shelf of the concept if they were all placed parallel to Re:Volt's driving direction at both the base upper shelf on the two extendable shelves.

### 5.2.10 Doors and Air Flow Blockage

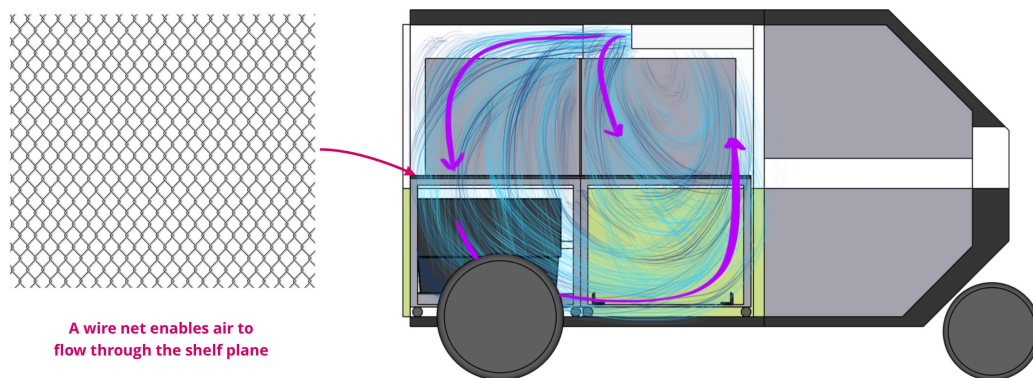
**Procedure:** Insights were collected on different door variants, with the focus being on doors to cooled cargo spaces in vehicles, see section 5.1.3.3 as well as other aspects to consider regarding the opening to a cooled space, see section 5.1.3. This was used to support ideas of how doors to the cargo space of Re:Volt could be designed, while taking the shelf structure concept developed into account. In addition to doors, the implementation of an air flow blocker was identified as beneficial from both a user and thermal energy retaining perspective. CAD software was thereafter utilized to visualize the design.

**Results:** Figure 5.28 illustrates how four doors could be implemented for the cargo space of Re:Volt. In that case, two of the doors would be placed in the back and the two remaining doors would be placed on the left and right side of the vehicle. The placement of the side door would be covering the area from in front of the wheel houses to behind the drivers cabin. The doors would be designed as the standard doors for cooled cargo spaces, in accordance to section 5.1.3.3. This entails, for example, being opened as a standard door with hinges along one of the vertical edges as well as the door being insulated and sealed. The side doors would at their furthest points extend 70 cm out from the vehicle and thus require less space than vehicles with a larger door radius.



**Figure 5.28:** Door concept for the cargo space of Re:Volt, enabling access to cargo held by the shelf structure concept.

In Figure 5.29, an assumption of the air flow circulation within the cargo space of the vehicle is illustrated. The exhaust of the evaporator unit part of the cooling system Frigo DC2500 points towards the back. The air intake is located at the bottom of the product. Thus, air would circulate from front to back of the cargo space. The air would also be able to pass through the upper shelf of the shelf structure concept if it was a net structure.



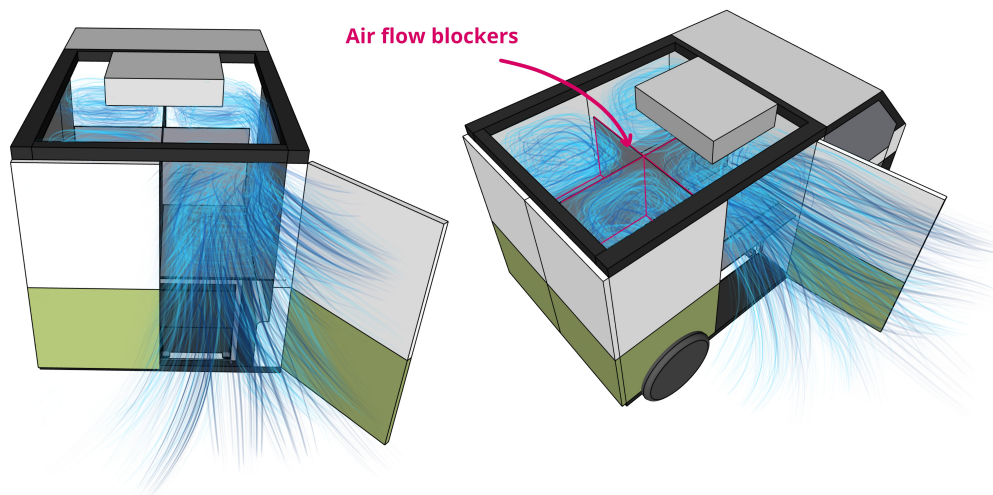
**Figure 5.29:** Air flow circulation inside of the cargo space of Re:Volt.

A continuation of the implementation of a middle divider on the upper shelf of the shelf structure concept placed lengthwise the cargo space was identified as beneficial related to the impact of door openings on the active thermal energy loss. The placing of an internal divider perpendicular to the closest door was found to potentially hinder an excessive amount of cold air escaping from the cooled cargo space when

doors are opened quickly and a vortex occurs, see Figure 5.30. It was considered that the implementation of dividers perpendicular to the closest door should not be too obtrusive so that they hinder air circulation within the cargo space when the doors are closed and thus being fully insulated. Another benefit of these air flow blockers was related to when unloading a paper bag from the upper shelf, identified as a potential risk area, see section 5.2.9.2. Here the air flow blocker could act as a divider of the upper shelf both lengthwise and transverse to the cargo space. This would limit the user to not reach too far into the cargo space, putting themselves in harmful lifting positions.

The usage of plastic stripes covering the door opening was another alternative identified to hinder cold air from leaving the cargo space when opening a door to the cooled cargo space. This was also seen in some direct observations, see section 4.1.5.5. This method of minimizing active thermal energy loss was considered to be intrusive and a hinder from a user perspective when loading and unloading goods from the cargo space and was not further investigated.

Two doors in the rear of the cargo space would divide the rear opening in two sections, which would reduce the size of one of these openings compared to if a single door is opened. As a result, it was presumed that a larger amount of cold air would then be retained during a door opening, see section 5.1.3.2.



**Figure 5.30:** Concept for implementing air flow blockers to reduce active thermal energy loss of cooled air when a door to the cargo space of Re:Volt is opened, with a visualisation of how the air circulation can be seen as intact when the cargo space is fully closed by making all shelves have a net structure.

### 5.2.11 Insulation and Geometry of Inner Wheel Houses

**Procedure:** Ideation regarding how insulation panels could be fitted inside of Re:Volt's cargo space. With a special focus on investigating how the insulation

panels around the wheel house inside the cargo space could affect the ease of implementation of a cooled cargo space as part of the production of the vehicle. Along with fitting with the dimensions of the shelf structure concept.

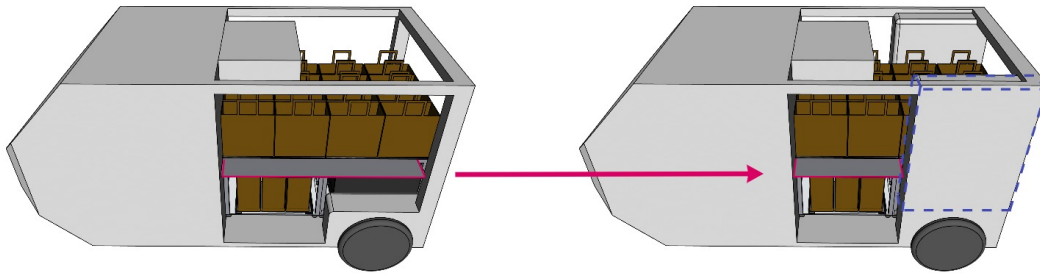
**Results:** The resulting suggestion was to extend the panels insulating the wheel-houses inside the cargo space upwards so that they would go all the way from the floor to the roof. The change would lead to an easier process to fully insulate the cargo space. This was mainly based in the number of smaller panels needed to be assembled to cover all sides of the wheel houses, as well as the complexity of insulating the rear two edges of the cargo space. These rear edges were shaped as large chamfers, see Figure 5.31, resulting in the insulating side panel and the insulating back panel not directly being connected and thus require a more complex design incorporating a third insulating panel placed diagonally between these panels.



**Figure 5.31:** Rear edge of the cargo space shaped like a large chamfer, affecting the design and placement of the insulating panels part of insulating the cargo space.

The thickness of the insulation had already been accounted for during the earlier ideation steps, so the change did not affect the dimensions of the lower shelf of the shelf structure concept. However, one exception to this was that the roof insulation of the vehicle could be thicker to combat the heat generated from the solar panel on top, which could reach 65°C (Boston Solar, 2019).

The new taller height of the wheelhouses affected the extendable shelves that were a part of the latest shelf structure concept. It resulted in a halving of the extendable shelves, see Figure 5.32, meaning that they would only be accessible from the side doors compared to the full length extendable shelves that can be seen in section 5.2.9.3.



**Figure 5.32:** Illustration over the halved extendable shelves at the sides of the shelf unit, as a result from the taller wheelhouses.

### 5.2.12 Additional Supportive Elements

Some design elements and aspects were considered related to the part function 'Supportive functions', part of the second iteration of the function tree created, see section 4.2.2. This part function was not prioritized when the part functions of the function tree were weighted against each other, see section 4.1.7.4. It was still seen as relevant to explore if any part functions part of 'Supportive elements' could be incorporated and met in the final design of the concept solution. An additional design element was also explored, being related to an identified problem area of the height of the user.

#### 5.2.12.1 Supportive Function: Offer Zone for Temperature Sensitive Products

**Procedure:** An additional use of the insulated boxes implemented as part of the freezer solution was identified in dialogue with the company iFoodbag.

**Results:** The result of an additional area of use identified for the insulated box part of the freezer solution, supported by dialogue with iFoodbag, was that the insulated box could be utilized to create a zone for temperature sensitive products during transport. This would require little modification. By simply leaving the PCM block out of the insulated box, together making up the freezer solution, makes the space within the box insulated against the surrounding, colder air in the cargo space. The shelf structure concept has a capacity for zero to four insulated boxes. Meaning that the need for a space for temperature sensitive products could be met if part of the lower shelf is used for this, instead of adding freezer capacity or utilizing the part of the lower shelf for placing paper bags directly.

### 5.2.12.2 Supportive Function: Having Cleaning Supplies Available Inside Re:Volt

**Procedure:** The supportive function of having cleaning supplies available inside of Re:Volt was expanded to also include storage of other relevant parts of a delivery, such as additional paper bags.

**Results:** A non-insulated shelf was included above the wheelhouses in order to utilize that part of the cargo space as well as meet the part functions of having some storage space available for for example cleaning supplies and extra paper bags. The need for a storage solution for extra paper bags easily available as part of the delivery vehicle was identified as part of the second interview with company representatives from the grocery delivery company Picmart, see section 5.1.1.2. The need for more simple cleaning supplies available as part of the delivery vehicle was identified in an interview with a transport manager for a larger company operating in the food E-commerce industry, see section 4.1.4.1.

### 5.2.12.3 Supportive Function: Support Delivery to Door

**Procedure:** The use of a hand truck to support the delivery of goods from the delivery vehicle to the end customer was observed during some of the performed direct observations part of the user studies, see section 4.1.5.5 as well as said to be included in larger vehicles active within the area of planned deliveries by one actor, see section 4.1.4.1. The inclusion of a hand truck in the cargo space of Re:Volt was investigated.

**Results:** It was found that hand trucks were mostly seen as included as part of vehicles used for larger, planned deliveries and seldom seen to be used as part of direct observations of unloading and delivery to door of planned deliveries carried out, see section 4.1.5.5 for a majority of the direct observations.

Based on the low priority of the supportive function of supporting and the limited amount of cargo space (see Requirement P.1 in 4.3), hand trucks were not investigated further. The decision was also supported by the decreased number of paper bags seen as the standard size of an order, that went from six bags to four (see section 5.1.1 to see why).

### 5.2.12.4 Step Stool

**Procedure:** A potential risk related to the height of the user was identified during physical tests with the full scale mock-up of Re:Volt and the shelf structure concept, see section 5.2.3.1. The result was that it was seen as more beneficial for the lifting position of the shoulder when unloading a paper bag from the upper shelf of the concept to be 180 cm than 172 cm.

**Results:** Based in the identified problem area of lower heights during unloading from the upper shelf of the shelf structure concept, a step stool was found to potentially act as an aid for users of a lower height. The intention being to get to a

lifting position more similar to the taller heights tested in the physical test using the full scale mock-up of Re:Volt and the concept, see section 5.2.3.1. The main reason being to put the shoulder of the user in a better position during the lift performed as part of unloading, also potentially offer the user an additional overview of the paper bags on the upper shelf.

The implementation of an additional, external part such as a step stool was considered undesirable based in the handling of a loose object that can be lost or misplaced within the cargo space. Another concern was that a step stool might pose an added risk of falling accidents part of the loading and unloading of the cargo space. Therefore, the implementation of a step stool was not continued further. It was seen as simple for customers of Re:Volt to implement a step stool type of support if seen as needed.

A limitation in investigating this area was related to the alternative solution of fastening some kind of stepping support on the vehicle. It was not possible to investigate the feasibility to implement this kind of design element based in regulations related to the vertical clearance between the lowest point of the vehicle and the ground, as well as the impact it could have on the stability and balance of the vehicle when used. It was therefore decided to not be an area investigated further.

### 5.2.13 Final Concept

**Procedure:** Areas that were explored during Research Phase 2 and Ideation Phase 2 as well as supported by earlier phases were combined to create a final concept. The final concept was thereafter created in the CAD software Autodesk Fusion 360.

**Results:** The final concept, see Figure 5.33 was a more detailed and refined version of the mid-concept of the second ideation phase, see 5.2.5. In addition to the two pull-out bottom shelves at the back of the shelf structure incorporated in this mid-concept, it had two additional pull-out bottom shelves at the front of the shelf structure that could be pulled out and accessed from the side of the vehicle. This consequently added four bags of order capacity, or an additional alvobox of 51 liters freezer space to each side. The final concept incorporated air flow blockers that also acted as dividers to segment the upper shelf into four quadrants. Moreover, a plastic grid with the ability to have its walls extend upwards was added to secure paper bags from moving. With the additional function to also aid the separation of orders that contains multiple bags, while keeping the flexibility in the sectioning high. Finally, it had a greater focus on considering Re:Volt's updated dimensions, geometry, and the required 30 mm thick insulation set to fully encapsulate the cooled part of the cargo space.



Figure 5.33: Visualization of the final concept.

### 5.3 Evaluation Phase 2

The aim of Evaluation Phase 2 was to assess the concept created in the middle of Ideation Phase 2, along with comparing the result of Ideation Phase 2 being the final concept with the requirements list.

#### 5.3.1 Mid-Concept Concept Evaluation with Picsmart

**Procedure:** The second semi-structured interview with Picsmart, see section 5.1.1.2 was used to gain feedback and insights around the Mid-Concept of Ideation Phase 2, see section 5.2.5 relative to the current operations of Picsmart.

**Results:** Picsmart’s product and assortment manager as well as the operations manager were very positive to the developed mid-phase concept and could not see any direct usability issues with it. Questions were asked and discussed around what the doors to the cargo space would look like, as well as ways to block cold air from escaping when the doors to the cargo space were opened. It was repeated from the first interview with the representatives of the company, see section 5.1.1.1 that it was undesirable to give away more expensive packaging elements such as the ifoodbag, currently used to deliver frozen products. Mainly based in the resulting economical

losses. Therefore, positive reactions were shared around the solution implemented in Re:Volt having a freezer space solution where it is possible to use more simple single-use packaging solutions, such as paper bags. This, paired with the use of an active cooling system for the entire cargo space, was seen as positive when compared to current concerns around keeping an unbroken cold chain during delivery, even in more extreme outside temperatures.

### 5.3.2 Comparing the Final Concept to the Requirements Lists

**Procedure:** The final concept in Ideation Phase 2, see section 5.2.13 was compared to the tables of requirements in section 4.1.7.5, to investigate if all of the requirements had been met.

**Results:** All of the requirements were found to be met by the final concept. For the explanations of how each requirements category was fulfilled, see Table 5.1.

**Table 5.1:** Evaluation of how the final concept met the requirements, divided into six categories.

Requirements category	Fulfillment of the requirements part of the category
Cooling	Met by the implementation of Dometic Frigo DC2500 (for cooling between 2°C and 4°C) along with iFoodbag alvoboxes (for freezing between -24°C and -18°C). Supported by design elements put in place to limit the active thermal energy loss during door openings of the cargo space, such as air flow dividers and door to the back opening being split up to become double doors.
Insulation	Fulfilled by lining Re:Volt’s entire cargo space with 30 mm insulation panels made out of polyurethane foam.
Physical Space	Met by optimizing the utilization of the cargo space by combining the two aspects of offering a cargo capacity identified as sufficient and providing a usability focused design of the final concept. Enabling the user to have easy access to all parts of the shelf unit and hence easy access to cargo. The unit being movable out of the cargo space also enabled simple cleaning of the space. The various use opportunities of the different shelves as well as dividers part of the final concept makes it easily adaptable for the current need, while seen to be a relatively simple, sturdy structure to offer a durable product.
Orders	Met by the inclusion of the larger air flow blocker that segmented the upper shelf into four quadrants, which made the separation and therefore identification of orders easier. The upwards extending plastic dividers supported the separation and securing of orders.
Physical Ergonomics	Fulfilled by the height of the upper shelf and the pull-out bottom shelves, that facilitated direct access to the handle of the paper bags as well as a more ergonomic position of the user during loading and unloading of paper bags part of a delivery. In addition, the implementation of the transportation dolly made the insertion and extraction of the shelf unit easier compared to alternatives such as lifting the shelf unit into the vehicle.
Administrative	Met with the implementation of the cooling system Frigo DC2500 since it includes the option to connect thermometers that can take continuous measurements of the air temperature in the cargo space to a central computer unit. This could thereafter be displayed to the courier and logged. The space above the wheel houses was made available to use as a storage space, for example to be used to store cleaning supplies or other necessities that could be needed during deliveries.

# 6

## Final Product

The final product was a movable shelf structure unit named Re:Load, see Figure 6.1. Re:Load was accompanied by a transportation dolly that enabled the shelf structure to be removed from the cargo space of the vehicle Re:Volt and thereafter rolled around in a warehouse or grocery store to enable pre-packing of goods outside of the vehicle. This could in turn aid a planned delivery process by eliminating the step of transferring groceries from a loading cart onto a second shelf unit inside the cargo space of a delivery vehicle. Another alternative available is that Re:Load could be left inside of the cargo space of Re:Volt, potentially more suitable for quick commerce applications with a larger number of different sites for loading the cargo space, while less orders would be needed to be loaded as part of a single delivery run.



**Figure 6.1:** Visualization of a man pushing Re:Load into Re:Volt (left), and a woman opening an alvobox (right).

Re:Load could house up to 32 standard paper bags of the dimensions 34x17x33 cm, intended for refrigerated goods with an additional four bags on the extendable top shelves. This results in a total capacity of the shelf unit being placed inside the cargo space of 36 standard paper bags, with 20 paper bags on the upper shelf and 16 paper

## 6. Final Product

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bags on the lower shelf. These bags would be stored in an environment with an air temperature of 2°C to 4°C, created using the cooling system Frigo DC2500.



**Figure 6.2:** Rendering of an alvobox that has been pulled out from the rear of Re:Volt.



**Figure 6.3:** Rendering of an opened side door of Re:Volt, showing the upper extendable shelf in a pulled out position.

The bottom shelf of the unit was split into four separate pull-out shelves. This division made it possible to either store 16 of the standard paper bags, or to store up to four alvoboxes depending on the freezer needs of a particular delivery. Each alvobox could respectively house up to three smaller paper bags of 14x25.5x31.5 cm. The bags inside the alvobox would be stored in an environment with an air temperature of -24°C to -18°C, created by the PCM block and insulating properties of the alvobox. Alternatively, an alvobox could also be used without the PCM block, which would make it suitable for the transportation of temperature sensitive goods. Re:Volt equipped with Re:Load can be viewed in Figures 6.2, 6.3, 6.4 and 6.5.



**Figure 6.4:** Rendering of Re:Volt with one side door and both rear doors opened, with three lower shelves in extended positions.



**Figure 6.5:** Rendering of Re:Volt that showcases the compartment located above one of the wheelhouses.

## 6.1 Use Case Scenario Examples

The way Re:Load would be used was seen to vary between different types of operations within the industry of E-commerce and last mile delivery of groceries, and it was deemed viable for both quick commerce and planned deliveries. Therefore, Re:Load was not designed with any particular of these industries in mind. On the contrary, it was designed to be able to serve both, with the difference being in how the user chooses to use the product. This section explain the necessary steps needed to use Re:Load for quick commerce and planned delivery purposes. The main difference being in the stages of 'loading of orders' and 'after delivery'. The base for

the operation was here called the base station.

### 6.1.1 Implemented for Quick Commerce

The following is a brief overview of the use case of implementing Re:Load together with the vehicle Re:Volt as part of an operation within the area of quick commerce.

- Prior to loading, at the base station
  - Decide the volume capacity of a freezer space for the shift and choose the corresponding amount of alvoboxes.
  - Place the chosen number of alvoboxes on the pull-out shelves part of the lower shelf.
  - If needed, replace the PCM blocks in the alvoboxes for fully solidified, frozen PCM blocks.
  - If relevant, put the old PCM blocks in the freezer.
  - Roll the shelf unit Re:Load into Re:Volt using a transportation dolly.
  - Pull out the extendable top shelves.
  - Leave the transportation dolly at the base station.
- During loading of orders
  - Load paper bags onto Re:Load being placed inside the cargo space of Re:Volt.
  - Pull up the dividers around the paper bags part of each, separate order.
- During delivery
  - Open up the door to the indented cargo.
  - Grab the paper bags part of the current order one by one.
  - Close the door to the cargo space.
  - If frozen products are part of an order, access the cargo inside the alvobox.
    - \* Pull out the alvobox.
    - \* Open the lid.
    - \* Rest the lid on the upper shelf.
    - \* Take out the paper bags part of the order.
    - \* Close the lid.
    - \* Push the pull-out shelf back into place.
- After delivery
  - In between different deliveries part of the same shift, Re:Load can be left inside the cargo space of Re:Volt.
  - After the final delivery of the shift when back at the base station, remove Re:Load from the cargo space from the opening at the back, using the transportation dolly.

- Perform a larger, daily cleaning of the emptied cargo space.

### 6.1.2 Implemented for Planned Deliveries

The following is a very brief overview of the use case of implementing Re:Load together with the vehicle Re:Volt as part of an operation within the area of planned deliveries.

- Prior to loading
  - Decide how many paper bags of frozen product are part of the delivery and choose the corresponding amount of alvoboxes.
  - Place the chosen number of alvoboxes on the pull-out shelves part of the lower shelf.
  - If needed, replace the PCM blocks in the alvoboxes for fully solidified, frozen PCM blocks.
  - If relevant, put the old PCM blocks in the freezer.
- During loading onto Re:Load
  - Load groceries into paper bags onto Re:Load being placed on the transportation dolly, in a warehouse or larger grocery store often in direct relation to the base station.
  - Pull up the dividers around the paper bags part of each, separate order.
- Loading Re:Load into the cargo space of Re:Volt
  - Roll the shelf unit into Re:Volt.
  - Pull out the extendable top shelves and place additional paper bags in them if there is a need for an increased capacity of up to four additional bags in the refrigerated space.
  - Leave the transportation dolly at the loading site.
- During delivery
  - Open up the door to the indented cargo.
  - Grab the paper bags part of the current order one by one.
  - Close the door to the cargo space.
  - If frozen products are part of an order, access the cargo inside the alvobox.
    - \* Pull out the alvobox.
    - \* Open the lid.
    - \* Rest the lid on the upper shelf.
    - \* Take out the paper bags part of the order.
    - \* Close the lid.

- \* Push the pull-out shelf back into place.
  
- After delivery
  - Remove Re:Load from the cargo space from the opening at the back, using the transportation dolly back at the base station.
  
  - Perform a larger, daily cleaning of the emptied cargo space.

## 6.2 Detailed Explanations of Re:Load's Parts

The following section goes into deeper explanation of the design of the different parts of Re:Load as well as some reasoning behind the chosen design.

### 6.2.1 Metal Main Frame

The main frame of Re:Load was chosen to be made up of a metal frame coated with a gray paint, see Figure 6.6. The aim of the coating was to protect the metal and to potentially limit the risk for the frame being unpleasant to touch, being too cold. The upper and lower shelf was set to have the same outer dimensions, being 900x1430 mm. The upper shelf was made of a metal wire net in order to aid air circulation inside of the cargo space as well as offering weight saving benefits in comparison to having solid shelves. The lower shelf was made up of four pull-out bottom shelves, see section 6.2.5. The main frame was set to have 20x20 mm thick legs, with a 20 mm high and 2 mm thick border around the edges of the upper and lower shelves. The unit could be rolled around on its four wheels, by having the user holding onto the wide, rubber coated handle at the back of the shelf unit. The frame was not an off the shelf solution and would therefore require additional design to prepare for manufacturing.



**Figure 6.6:** Metal main frame part of Re:Load.

### 6.2.2 Extendable Upper Shelves

Attached to bottom of the upper shelf at the front half of the shelf unit were two extendable shelves, covering the width of about half the long side of Re:Load, see Figure 6.7. These extendable shelves were like the shelves part of the main frame made of a metal wire net, with their outwards facing surfaces painted in a mint green. The colour was there to make it clear to the user that the surfaces part of the extendable shelf are points of interaction. When extended, each shelf could house up to two additional paper bags each, see Figure 6.8.



**Figure 6.7:** Extendable upper shelves.

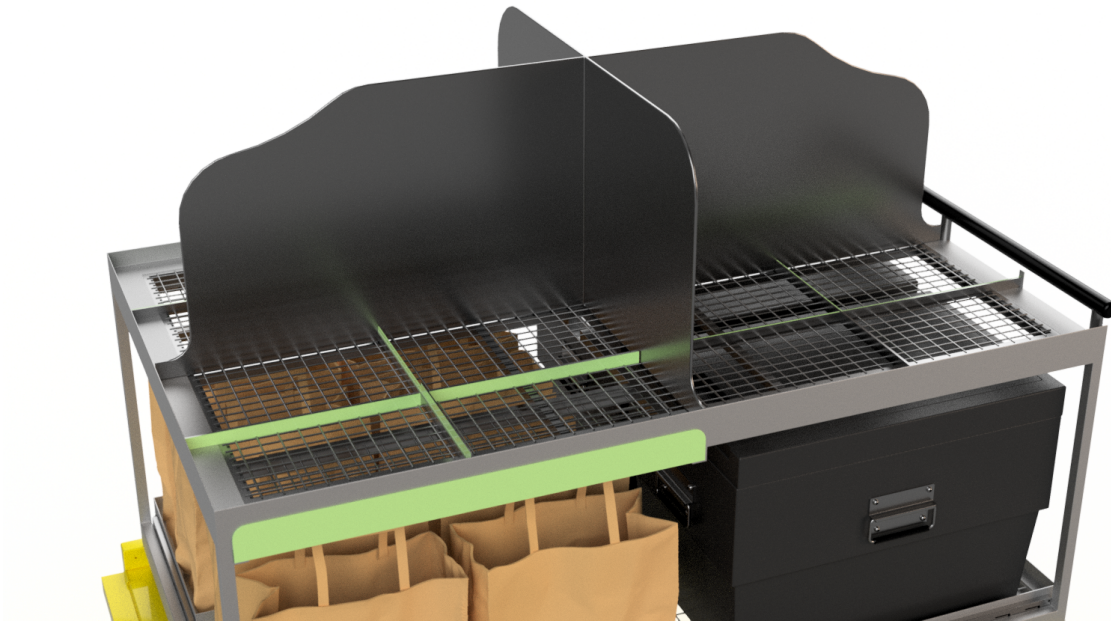


**Figure 6.8:** Extendable upper shelves with paper bags.

### 6.2.3 Air Flow Blocker

The air flow blocker was a structure made of plastic placed on top of the upper shelf, dividing the upper shelf into four quadrants. This structure had a combined function. One being to limit the active thermal energy loss in the form of cold air being pulled out of the cargo space when a door to the cargo space was opened. The

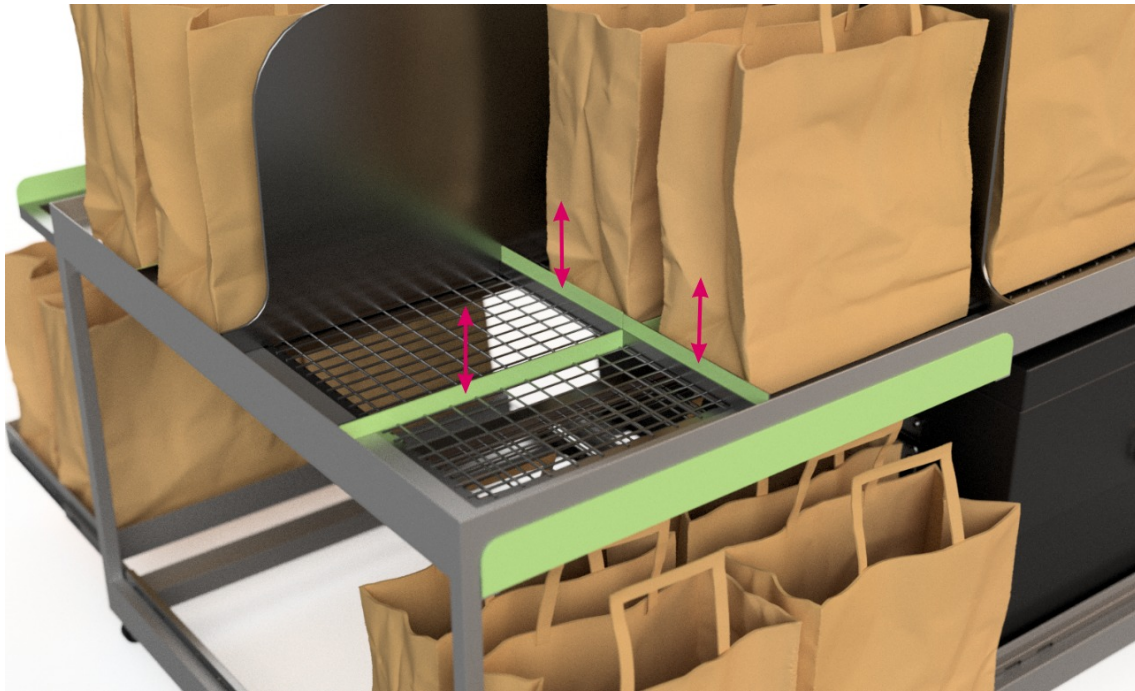
other being to limit the user in how far into the cargo space the most inner row or paper bags possible to access was placed, in order to minimize sub-optimal lifting positions made by the user. To support an easy implementation, a more simple replacement process as well as offering a more flexible solution, the air flow blocker was set to be firmly fastened but not permanently installed.



**Figure 6.9:** Air flow blocker.

#### 6.2.4 Dividers

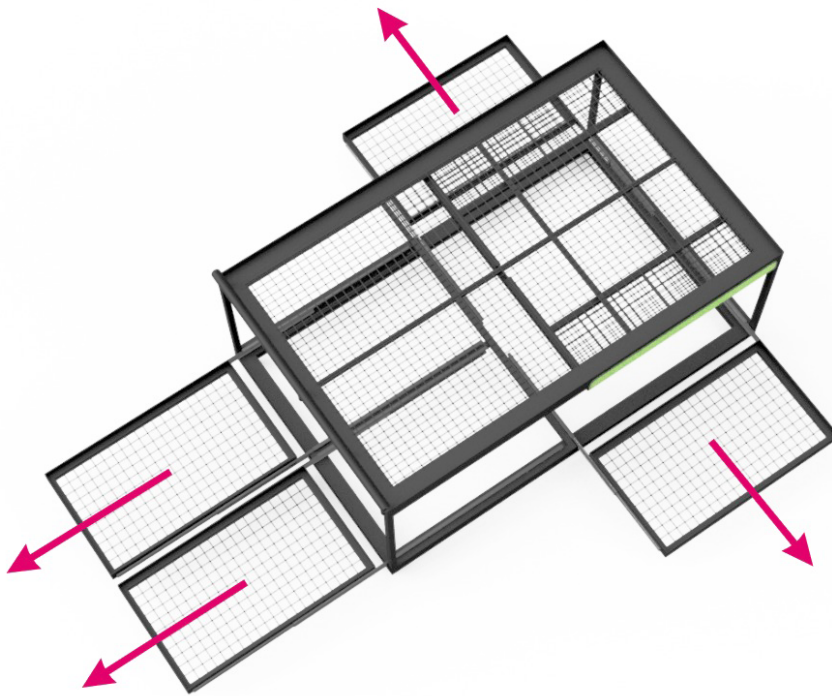
Attached to the top side of the upper shelf was a grid of dividers, one placed in each quadrant made by the air flow blocker structure, see Figure 6.10. The grid, being 20 mm tall were made of a static cross, with each arm of the cross having a second, movable part that could be extended 18 mm upwards. These were set to be made out of plastic, with all movable parts being green in order to indicate possible points of interaction to the user. The dividers would mainly act as a way to secure paper bags from moving during transport. While also offering the function of a flexible way to group paper bags part of the same order through extending the dividers surrounding the paper bags part of each order. To support an easy implementation, a more simple replacement process as well as offering a more flexible solution, the dividers were set to be firmly fastened but not permanently installed.



**Figure 6.10:** Dividers to secure and separate orders on the upper shelf of the shelf unit.

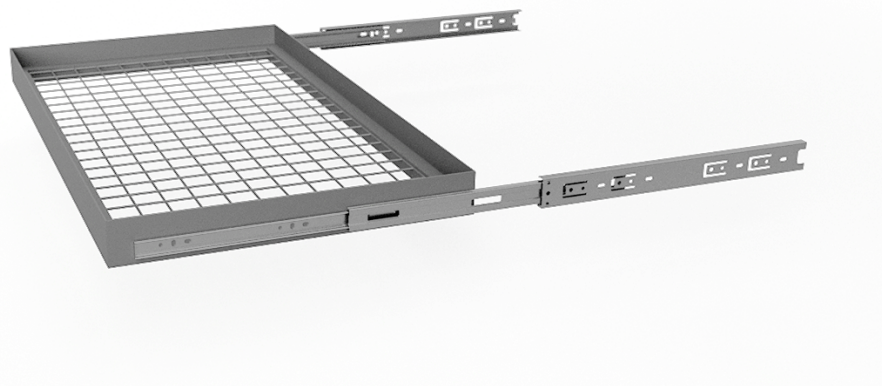
### 6.2.5 Pull-out Bottom Shelves

The lower shelf of the shelf unit consists of four pull-out shelves, see Figure 6.11.



**Figure 6.11:** Pull-out bottom shelves.

All of the bottom shelves were identical with dimensions of 400x680x40 mm, see Figure 6.12. The motivation behind making all four shelves of the same dimensions was to support manufacturing. The pull-out function was offered by having the shelves being fastened on telescopic rails, 350 mm and 700 mm long respectively depending on if they were extended to the sides or the rear of Re:Load.



**Figure 6.12:** Lower shelf with telescopic rails.

The pull-out shelf could either carry four standard paper bags, or one alvobox with

three smaller paper bags, see Figure 6.13. The alvobox would be magnetically attached to the shelves.



**Figure 6.13:** Pull-out bottom shelf carrying four standard paper bags (left), and a pull-out bottom shelf carrying an alvobox (right).

### 6.2.6 Freezer Space: Alvoboxes

The alvobox is an off-the-shelf product offering a space of 51 liters per box where an air temperature suitable for frozen goods is created by inserting a PCM block in the lid, see Figure 6.14. The implementation of placing alvoboxes on the pull-out bottom shelves enable a flexible configuration based on the need for the imminent delivery. The capacity referred to when Re:Load was placed inside the cargo space with the extendable shelves loaded with two paper bags each, resulting in 20 paper bags stored on the upper part of Re:Load.



**Figure 6.14:** Illustration of how the alvobox can be opened during a delivery (top) and a sequence of how the PCM block is inserted into the lid of an alvobox.

### 6.2.6.1 Main Configuration

The main configuration was seen to be two alvoboxes at the back of the shelf unit, accessed from the back side of Re:Volt, see Figure 6.15 . This averages to 102 liters or six smaller paper bags of freezer capacity. The other two pull-out bottom shelves would then be available to use for standard paper bags, making the maximum capacity for standard paper bags in the refrigerated area 28 bags when utilizing the extendable shelves part of the upper shelf. If following the identified number of bags seen as part of a standard order, this equals to a maximum capacity of seven orders. Based in the insight that most orders include some kind of frozen goods, it was estimated that the two alvoboxes would in most cases offer a sufficient freezer capacity.



**Figure 6.15:** Main configuration of alvoboxes and bags on the lower shelf of Re:Load.

This main configuration that contains two alvoboxes could be changed by placing the boxes in the front of Re:Load instead of the rear, but that alteration could potentially lead to more walking around the vehicle for the courier. The reasoning behind this was that a customer could have ordered two bags with frozen groceries that in turn could be placed in different alvoboxes. If the boxes thereafter were placed on opposing sides of the vehicle, the courier would have to walk a longer distance compared to if the boxes were placed right next to each other. Thus, it was recommended that they were placed in such a manner.

### 6.2.6.2 Alternative Configurations

There are four different alternative configurations to the main configuration of how the pull-out bottom shelves are utilized, with the capacity referring to when Re:Load is placed inside the cargo space with the extendable shelves part of the upper shelf in use. These can be seen in Figure 6.16 from left to right and are:

- Zero alvoboxes, where all four pull-out bottom shelves are utilized for standard paper bags in the refrigerated space, resulting in a maximum capacity of 36 standard paper bags and no freezer space available.
- One alvobox, where three of the pull-out bottom shelves are utilized for standard paper bags in the refrigerated space, resulting in a maximum capacity of 32 standard paper bags and a freezer space of 51 liters or three smaller paper bags.
- Three alvoboxes, where one of the pull-out bottom shelves are utilized for standard paper bags in the refrigerated space, resulting in a maximum capacity of 24 standard paper bags and a freezer space of 153 liters or nine smaller paper bags.
- Four alvoboxes, where none of the pull-out bottom shelves are utilized for standard paper bags in the refrigerated space, resulting in a maximum capacity

of 20 standard paper bags and a freezer space of 204 liters or 12 smaller paper bags.



**Figure 6.16:** Different amounts of alvoboxes loaded on the bottom shelves of Re:Load.

### 6.2.7 Transportation Dolly

The transportation dolly was made up of a metal frame, used as a way to remove Re:Load from the cargo space of Re:Volt, see Figure 6.17. This is done from the back side of the cargo space. The development of the transportation dolly was not investigated in as much detail as the rest of Re:Load.

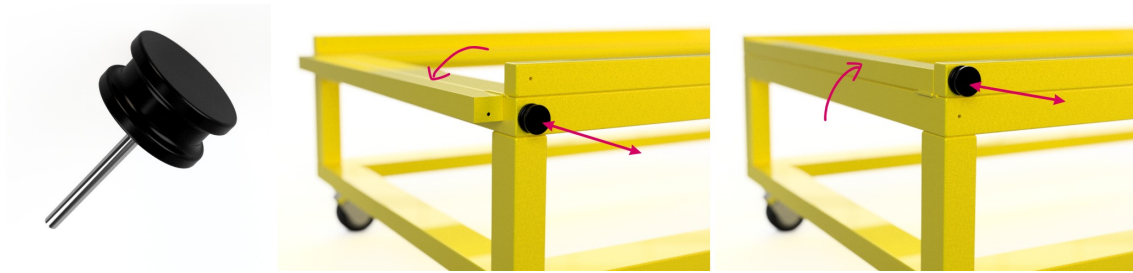


**Figure 6.17:** An empty transportation dolly (left) and a fully loaded transportation dolly (right).

At the front of the transportation dolly, by the front wheels of the metal main frame of Re:Load, a manual locking mechanism was implemented so that Re:Load would be secured onto the transportation dolly when being moved around outside of the cargo space, see Figure 6.18. The locking was achieved by pushing a metal rod into holes at the side of the dolly that in turn magnetically attached itself to the metal frame.

## 6. Final Product

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**Figure 6.18:** The manual locking mechanism at the front of the transportation dolly.

The transportation dolly had four lockable wheels and was designed so that you can walk into it when pushing and pulling Re:Load in and out of the cargo space, see Figure 6.19. It also had larger wheels than Re:Load, to make its rolling capability smoother over small bumps, cracks, or other obstacles in the ground.



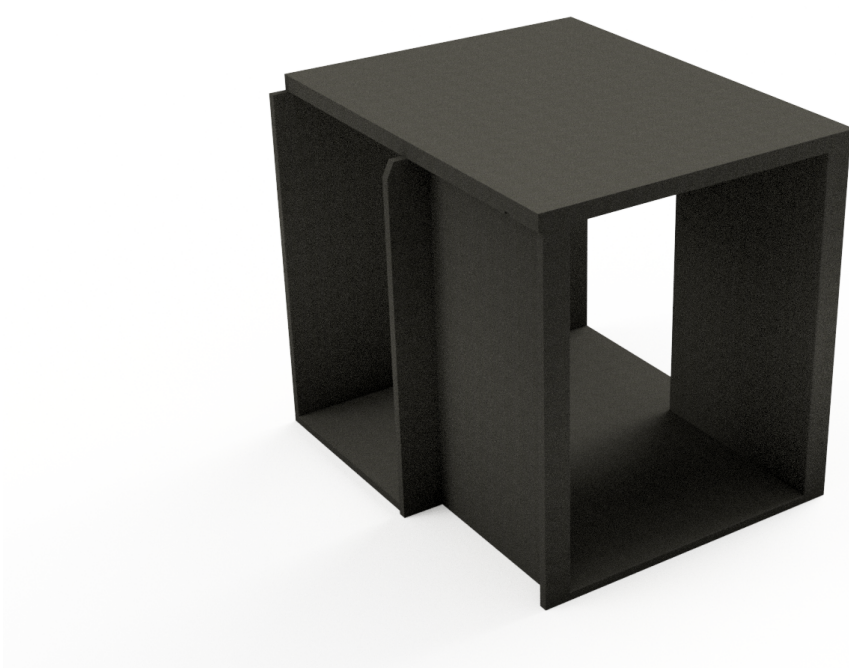
**Figure 6.19:** A fully loaded Re:Load pushed into the cargo space using the transportation dolly.

## 6.3 Other Design Elements Part of the Cargo Space

The focus was put on the design of Re:Load, but some design elements were also considered in relation to the overall design of the cargo space of Re:Volt. Covering the insulation of the cargo space, access to the cargo space through doors and the utilization of non-insulated spaces of the cargo space.

### 6.3.1 Insulation

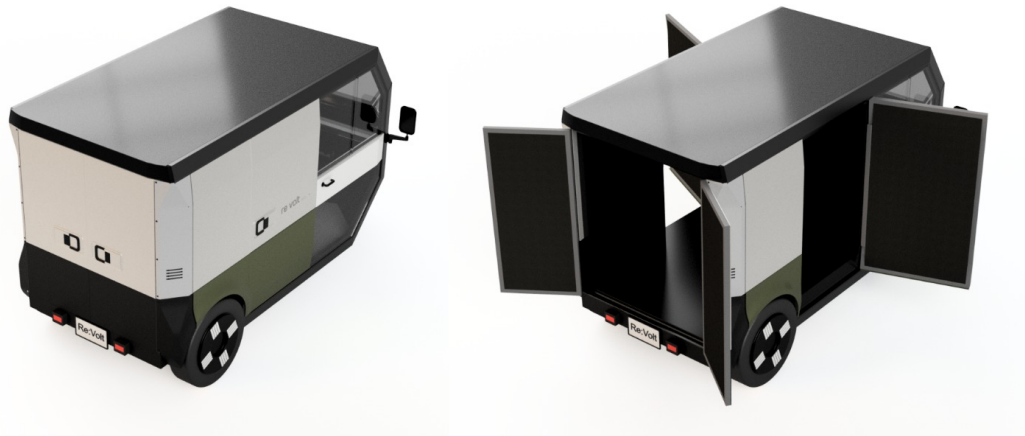
The inside of the part of Re:Volt's cargo space intended to be cooled was fully lined with insulation panels made of 30 mm polyurethane foam, with the exception of a 50 mm thick panel in the top of the vehicle where a solar panel would sit (see Figure 6.20). In order to create a fully insulated cargo space, no metal frame was exposed to the cold air inside of the cargo space. The main reason being to reduce the risk of passive thermal energy leaks through conduction.



**Figure 6.20:** Insulation panel structure inside of Re:Volt's cargo space.

### 6.3.2 Doors to the Cargo Space

The design of doors and corresponding openings to the cargo space was driven by several factors. The two main factors being to offer easy access to all goods as well as limitations part of the physical structure of the vehicle, mainly related to the wheelhouses and the frame structure of Re:Volt. The doors were also seen as a means to limit the active thermal energy loss during door openings to the cargo space. The cargo space was set to have four doors, all being insulated and satisfactory sealed. One on each side as well as a double door at the back of the cargo space. These were accessed using a standard door handle, observed to be utilized in delivery vehicles.



**Figure 6.21:** Doors for a version of Re:Volt that is designed with a cooled cargo space.

### 6.3.3 Compartments Over the Wheelhouses

The insulation around the wheelhouses was set to extend upwards to the inner side of the roof, instead of directly following the internal walls of the wheelhouse. The main driver for this was to support the production of the cargo space and the installation of the insulation panels, since the extended panels by the wheelhouses would consist of two large insulation panels rather than several smaller ones required to cover the wheelhouse and adjacent wall. In addition, the non-insulated space above the wheel houses was utilized as storage compartment (see Figure 6.22) with three shelves each, possible to access from the side of the vehicle and closed off by a simple door cover opening upwards. Intended to be used for relevant parts of the delivery such as additional paper bags and more simple cleaning supplies.



**Figure 6.22:** Storage compartments located above the wheelhouses in Re:Volt, accessed from the sides of the cargo space.

# 7

## Discussion

The chapter discusses the final solution in the project, involved parties, credibility of sources, ethical issues, and sustainability aspects.

### 7.1 The Success of the Design

In this section, different aspects of the success of Re:Load implemented in the cargo space of Re:Volt are discussed.

#### 7.1.1 Comparison of Solution Against Use Cases and Market Segment

Re:Load as a solution implemented in Re:Volt has some discrepancies with the targeted market segments. When used for quick commerce, it is intended to stay inside of the cargo space. Re:Load can then be seen to have its maximum loading capacity, mainly driven by the two extendable shelves part of the upper shelf. This can be put in comparison with the identified use case within quick commerce, where the speed and easy access to goods were generally prioritized over a maximized capacity. The extendable shelves can, on the other hand, be seen to also support speed and easy access through moving the edge of the available shelf space closer to the edge of the cargo space. Thus enabling the use of shelf space closer to the user during loading and unloading.

Re:Load when used as part of planned deliveries was seen to have a slightly lower loading capacity compared to when implemented as part of quick commerce. This was based in the pre-packing of goods part of that type of operation, thus being unable to use the extendable shelves part of the upper shelf. This can be seen as somewhat of a discrepancy with the identified priorities of operations working with planned deliveries. A high loading capacity in the number of orders, based in volume or weight as the limiting factor, was seen to be raised as the main priority. The distribution of freezer space available using the main configuration of having two alvoboxes was seen to be slightly more fitting with the different estimates for the freezer space required per order and delivery relative the number of paper bags seen as a standard order part of planned deliveries. Planned deliveries were seen to have a standard order size of six paper bags. If using the main configuration of two alvoboxes, the main capacity is then six orders per delivery where four orders consists of five standard paper bags and one bag of frozen products, and two orders

consists of four standard paper bags and one bag of frozen products. Corresponding to the slight variation in order size and distribution or product types.

### 7.1.2 The Optimal Use Case and Market Segment

The optimal use case for Re:Load part of Re:Volt was discussed. The solution was seen as possible to be implemented in both operations of planned delivery and quick commerce, and its optimal use case was identified as a middle ground of these two, being planned deliveries with a shorter time frame between order and delivery of 2–3 hours. The main reason being to keep the orders stacked to increase efficiency of each delivery, but not requiring a much larger capacity for each delivery round like the current, larger operations of planned deliveries. It was also assumed that the average order of this type of delivery might be closer to those part of quick commerce than planned deliveries, resulting in smaller standard orders and thus increasing the number of orders possible to fit into one delivery round. One market trend identified within the area of planned deliveries was the potential, future implementation of micro distribution centers in an urban environment. This could be seen as a possible application of the use case identified as optional for Re:Load together with Re:Volt.

One identified alternative was to add an element of quick commerce to this kind of operation, as another way to increase the utilization of each delivery round. These two alternatives were not seen to be implemented in the current market of last mile delivery of groceries, taking the limitations of this thesis project into consideration that all global markets were not possible to investigate.

### 7.1.3 Prevention and Recovery of Potential User Errors

The solution can be seen to be part of the delivery process where there are several interaction points between the solution and the user. There are some heuristics available related to user errors occurring as part of this interaction, some of which cover the use of design for user error prevention and recovery (Nielsen, 2020). There are several ways the solution can be seen to support a prevention and avoidance of user errors. One example being the shelf with paper bags on it being movable throughout the loading stage of cargo part of a delivery process, instead of moving paper bags part of orders several times between shelves. This does not only lower the manual handling required but does also lower the potential risk for misplacing paper bags. Additional aspects of where to place the paper bags part of different orders were not further considered in this project. Another aspect of Re:Load seen to support the prevention of user errors was the implementation for air flow blockers, in addition to be intended to limit the active thermal energy loss from the cargo space also limit the user from putting itself in potentially harmful working positions, part of the loading and unloading of goods onto Re:Load.

There are several areas of potential user error that can be identified as part of the final solution of Re:Load and the design of the cargo space of Re:Volt. One is related

to the daily operation of keeping the freezer space functioning, where a step in the routine can potentially be missed. This was related to the replacement of the PCM block in the freezer space in order to keep the air temperature at a satisfactory level, where a fully frozen PCM block should replace one that has already gone through a phase-change to liquid and thus having a lower cooling capacity. This error can be seen as difficult to recover from after leaving the base station, since it requires access to additional, fully frozen PCM blocks. This was seen as an area possible to address through a set routine as part of a delivery round.

Two potential user errors were identified related to the removal of Re:Load from the cargo space. One was if the shelf structure is attempted to be removed from the cargo space without the transportation dolly. The risk being that the shelf structure of Re:Load falls out of the cargo space when no support is given over it. It was seen as difficult to recover from that kind of situation, deemed to be an user error more suitable to strive towards preventing. One way of prevent this user error would be to introduce a mechanism of locking the position of Re:Load inside of the cargo space of Re:Volt until the transportation dolly is securely attached to the back of the cargo space. The other potential user error related to the removal of Re:Load could be if the extended shelves part of the upper shelf were not to be put back into a retracted position. This would result in the shelves physically colliding with the insulation panels around the wheelhouses. Potentially resulting in some damage, that might pose a risk for a decrease in insulation properties over time based in the loss of the gas within the insulation panels. It was seen, based in the short distance between the back side of the extended wing and the front side of the internal wall structure around the wheelhouse that the user would feel the obstacle present when pulling out Re:Load, potentially acting as a reminder of what kind of error was performed and how to recover from it by retracting all extended shelves. Based in the short distance between the shelf and the wall structure, the force of which the shelf unit hits the wall structure was seen as likely to be small and to have a relatively low impact. Still, this potential user error can be seen to support a material choice of the lining of the inner wall structure to be able to stand some impact.

## **7.2 The Involvement of Different Stakeholders in the Project**

Throughout the project, the more in-depth interviews have generally been held with people responsible for the operations or logistics of some E-commerce for home delivery of groceries. The direct observations made have, on the other hand, had a large focus on users being couriers delivering groceries packed in paper bags. These direct observations have generally been followed up by a shorter, unstructured interview with the courier.

This division of types of data gathering has resulted in different kind of insights. This was mostly seen as successful, in regards to qualitative data that was gath-

ered throughout the different phases of the project. The selection of participants for interviews and observations was mainly based in targeting stakeholders holding a role at a company within the industry, all seen as relevant. Based in what the organizational structure looked like at many of the companies with whom contact was made with for interviews, especially the larger organisations, a certain level in the hierarchy was gained access to. This resulted in most of the more in-depth interviews being held with people having a role with more responsibility, a strategic perspective and more oversight over the operations. This was one of the main contributors to the lack of in-depth interviews connected to the couriers. The couriers being seen as a main user group in the thesis project. This also had an influence on the quantitative data gathered on this user group, where direct observations and shorter interviews were instead utilized.

Another contributing factor was the limited number of relevant people available to get answers from. An operation similar to the intended use case for Re:Load part of Re:Volt using a delivery vehicle of a similar size as Re:Volt has not been seen as part of any E-commerce operation of groceries identified within the thesis project. In order to combat this, a larger width of stakeholders were involved in the project. Covering both those responsible for the delivery operation such as transportation manager and operation manager as well as users such as couriers for home delivery of groceries. Both planned deliveries and quick commerce were included.

A majority of the companies targeted in the performed data gathering were selected based on them being the largest actors in the Swedish food retail industry, with an established E-commerce of groceries as either their core business or as one part of it. Especially for those active within the area of planned deliveries, generally found to be larger companies overall compared to those active within the quick commerce. One potential reason for this was seen as the novelty of the quick commerce sector in Sweden, active within the last mile delivery of groceries. Where the larger food retail companies active within planned deliveries can be seen as being more established.

### 7.3 Conflicting Needs and Requirements

A conflict was identified regarding the needs and requirements, where the delivery companies wanted to maximize earnings and have a solution that fit into the current operations, whilst the user wanted good working conditions. These working conditions where the interactions with the developed solution that was supposed to have high usability from a cognitive- and physical ergonomics perspective as well as being sustainable to work with long term. More specifically, a cargo space that is intended to have a high usability can stand in conflict with capacity related to volume and weight efficiency. Aspects of the physical ergonomics of the solution were found to discourage the placement of cargo over a certain height and introduced the need for shelves. Adding complexity of the structure as well as weight. This usability in interactions with the cargo space might also stand in conflict with aspects related to the efficiency and energy conservation. Mainly related to the part of delivery where the door to the cargo space is opened as well as the several doors

incorporated to offer access to goods within the cargo space. Another conflict seen related to the most efficient and energy conserving cargo space design for cold goods was how it might somewhat stand in conflict with maximizing the available cargo space, based in the insulation needed. Another identified conflict was related to the production of the solution, in that some materials with sought properties, such as being lightweight and of high strength come at a higher cost. This area was not included to be investigated in detail in the thesis project, due to time limitations.

## 7.4 Credibility of Sources and References

The section discusses potential biases from company representatives and the credibility of sources considering some of the rules and regulations relevant to the industry of last mile delivery of food products.

### 7.4.1 Potential Biases

Interviews held with people at Dometic and iFoodbag could have resulted in skewed perceptions of how their products were perceived, since these people were company representatives and would most likely like to favour their products and put them in good light. Therefore, additional research (in areas where possible) was made to verify claims as well as into some comparable product alternatives. This was also found to be the case for other research, such as video observations conducted by analysing videos on YouTube.com. These videos were in turn uploaded by the food retail and delivery companies themselves. Therefore, they might have orchestrated and shown their delivery process in ways that seem better than what it looks like in reality. To combat this, the video observations were used in conjunction with qualitative interviews and other real life observations to cross reference and built onto the data.

### 7.4.2 The Considered Rules and Regulations

A large aspect regarding rules and regulations considered covered the transport of groceries, with a focus on products with some temperature requirements. A majority of these rules and regulations chosen to adhere to in the project were published by a large, national trade association for the industry of fast-moving consumer goods in Sweden called the Swedish Food Retailers Federation (Svensk Dagligvaruhandel, n.d.). This document was also seen as approved by the Swedish Food Agency by being made available through their website (Livsmedelsverket, 2021). The regulations and recommendations published by a national agency were also referenced regarding the area of work environmental law, from the Swedish Work Environment Authority. Therefore, both of these sources were deemed to be credible.

### 7.5 Ethics

There are some different groups of people affected by our investigation, development and result of this project. The main ones can be seen to be personnel for packing of goods in the form of groceries as well as loading the cargo into a delivery vehicle, couriers for home delivery of goods responsible for the driving and delivery of goods, customers receiving groceries ordered online as well as people responsible for the logistics and similar at companies offering home delivery of goods including products that have lower temperature requirements.

#### 7.5.1 Designing For the Intended Users

The final solution was designed for people of the 5th to 95th percentile, referring to people that are statistically average when it came to height and physical capability. This might not have been the most ethical decision in regards to universal design, or design for all, meaning that every person in a society should have the same possibilities in life (National Disability Authority, n.d.). One reason to why the statistically average people were targeted in this project was there were limitations of the vehicle itself related to universal design. In most cases, a person has to be able to enter the vehicle and drive it in order to work as a courier. Therefore, it was deemed unsuitable to aim towards a fully inclusive design of Re:Load as the solution to be implemented in Re:Volt. In addition, it might have caused the solution to become overly complex and expensive. For example if it had been designed so that anyone could reach every part of the shelf unit. Additionally, the fixed dimensions of the paper bag set as standard as well as other grocery bags and boxes seen to be used for deliveries was also found to pose problems when it comes to a solution fully adapted for all, since they only can be configured in a finite amount of ways. Thus, the decision to design for the 5th and 95th percentile could be deemed realistic and reasonable, based on the targeted user group within the last mile delivery industry.

#### 7.5.2 Advantageous Height Characteristics of the User

Part of the design of Re:Load can be seen as a direct consequence of pre-determined physical limitations of Re:Volt. Some of these being the internal height of the cargo space of Re:Volt and the loading height of the floor in the cargo space from the ground, affecting the placement of the two shelves part of Re:Load. Additionally, aspects related to the dimensions of a standard paper bag and the clearance identified as necessary above the handles of this bag could also be seen as part of this. An additional constraint was that the design of the lid of the alvobox implemented to offer a freezer space resulted in a pull-out bottom shelf being required.

The consequences of these pre-determined physical constraints of elements implemented such as the cargo space of Re:Volt, the paper bag and the alvobox on the design of Re:Load also had another effect on the usage of Re:Load. This being that as part of the use of Re:Load it can be seen as slightly advantageous to be a taller person of around 180 cm, see section 5.2.3.1. This can be seen to result in a usage

of Re:Load with having a good overview of the bags on the upper shelf as well as a favorable position of the shoulder when lifting the paper bags from this upper shelf. The pull-out bottom shelves could also be utilized well to more easily access to the goods placed on the lower shelf.

## 7.6 Sustainability Aspects

One of the United Nations global goals that have been relevant to this project was goal number 11, which is called *Sustainable Cities and Communities*. To develop a sustainable alternative for urban transport and home delivery of groceries can be seen as minor but related to support this (UNDP, n.d.). The following are some areas related to the sustainability of the final solution.

### 7.6.1 Re:Volt as a Delivery Vehicle in an Urban Environment

There are both positive and negative aspects identified related to the use of Re:Volt as a delivery vehicle, from a societal as well as environmental sustainability perspective. On one hand, it is a vehicle with a top speed of 45 km/h in most cases. This could pose issues when the vehicle share the road with faster moving vehicles such as cars, potentially resulting in dangerous traffic situations where other drivers take risks in order to avoid getting stuck behind Re:Volt or if they consider themselves to be stuck behind it as a slower moving vehicle. The vehicle can not be used on other types of roads, such as bike lanes. However, there are many positive aspects to be seen with the use of Re:Load part of Re:Volt related to it offering a more sustainable alternative for the last mile delivery. For example, replacing more heavy delivery vehicles, especially those with an internal combustion engine (ICE). It could also potentially replace less efficient last mile delivery alternatives, such as people driving to the store in their own private cars. Since Re:Volt as a singular electric vehicle could potentially take the place of many cars during one delivery round, with these cars also potentially being ICE vehicles. This further supports the use case of Re:Load part of Re:Volt where several orders are stacked together and delivered as part of one delivery round. With it being an electric transport option, the usage can also be seen to result in a decrease in both noise pollution and other type of pollution such as greenhouse gas emissions, in comparison with using ICE vehicles.

### 7.6.2 Reduce Food Waste Part of The Last Mile Delivery

According to the UN, food loss is responsible for around 15% of the total related CO<sub>2</sub> emissions when looking at the whole food supply chain. Part of this is related to issues around cold storage and transport. It is mainly identified as an issue closer to the source of the food production, but importance is also put on the offering of an unbroken cold chain throughout the delivery process (UNEP, 2020). The developed solution can be seen to be part of offering an unbroken cold chain part of the last mile delivery. Ensuring product safety and high quality of food products delivered,

through ensuring a satisfactory temperature. Covering both direct impacts, regarding for example keeping bacteria growth during transport to a minimum, as well as the shelf life and risk for food waste of the products at the end customer. For example related to a more rapid decrease of product quality over time that could result in higher food waste. This is especially important regarding more sensitive products with stricter requirements, such as food products from an animal origin (Food Safety and Inspection Service, 2020).

Another area identified to potentially support low food waste at the end consumer was how the dividers implemented as part of the shelves in Re:Load support the physical integrity of the paper bags used to transport groceries, securing them in place. This can be seen as a way to limit the mechanical stresses that might be put on food products as part of the transport, especially affecting the perceived quality of fruit and vegetables (Tanner, 2016).

The cooled cargo space can also be seen to have some adverse effects on perceived food quality and resulting food waste. There is no area reserved for temperature sensitive products in the main configuration of Re:Load. This can be seen to affect both the shelf life as well as resulting food waste, based in chilling injury of products during transport. This mainly affects products such as those of tropical origin, one example being bananas having their peel turning brown (Food Safety and Inspection Service, 2020; McGee, 2007). The affect of product quality is also generally noticed first when the product is transferred back to a non-cooled area, resulting in a potential food waste effect first at the end customer after the delivery (Food Safety and Inspection Service, 2020). This was an identified problem part of thesis project but was not prioritized. The solution developed can be seen to partly offer a solution to the issue of potential chilling injury of some products during delivery. The solution being that Re:Load offered a flexible capacity of alvoboxes from zero to four, placed on the lower shelf. This enables a higher capacity of insulated boxes available to implement during one delivery than what is seen as generally needed when it comes to freezer space. Therefore, alvoboxes could also be used without PCM blocks to create a space insulated from the cooled cargo space, making them suitable to store room temperature goods.

### 7.6.3 Single Use Paper Bags

A potential issue when it came to sustainability aspects of the final solution was the utilization of paper bags, since they might not be regarded as fully reusable products. Many discussion were held during the development of Re:Load, to incorporate a fully reusable alternative to paper bags to reduce the amount of disposable paper. This was also desired by Picmart that were looking into new solutions for their quick commerce deliveries. However, paper bags were incorporated instead since it was believed that they in turn could lower the threshold for potential adopters of Re:Load, because they were identified as a standard solution within the modern day food delivery industry. With that said, it was also hard to determine if a fully reusable product such a plastic box for example, would result in less overall emissions

than a large amount of disposable paper bags would. Therefore, it was not possible to conclude if paper bags were a less sustainable option than other fully reusable alternatives.

#### **7.6.4 Energy Loss**

An area of concern regarding energy loss related to some of the different use cases of Re:Load together with Re:Volt were identified. This area being that thermal energy could be lost if Re:Load is moved in and out of the cargo space. For example, having Re:Load being removed from the cooled cargo space part of the loading stage during a planned delivery, heating up in the ambient temperature outside of the cargo space, to then having Re:Load being inserted into the cooled cargo space again. Mainly based in the metal of Re:Load unavoidably exchanging thermal energy with the cold air inside of the cooled space, meaning that moving the structure in and out of the cooled cargo space to an environment of a higher temperature would result in lost thermal energy and requiring the cooling system of Frigo DC2500 to work harder. On the contrary, Frigo would not have to work as hard if Re:Load already had a lower temperature of around 2–4°C when being inserted. It was identified as beneficial if the surface coating of the metal frame could have a property to decrease the thermal energy retention of the physical structure of Re:Load. Potentially resulting in a prolonged time for the structure of Re:Load to change temperature, seen to positively affect the impact on energy loss from moving Re:Load in and out of the cooled cargo space of Re:Volt.

#### **7.6.5 Battery Usage**

The battery usage of Re:Volt as an electric vehicle as well as the increased strain put on the battery from having an active cooling system installed in the cargo space can be discussed. One result of this cooling system might be that a larger battery with a larger capacity is chosen to be implemented in the delivery vehicle (W. Collings, personal communication, 2022).

In an electric vehicle the battery can also make up a large proportion of the vehicle's total weight, which can be seen as a negative aspect. However, the increased use of electric vehicles is pushing battery technology forward. Current research and development around battery technology will hopefully add to lowering the negative impact of batteries in vehicles in the future (Berjoza & Jurgena, 2017).

### **7.7 Future Research**

Some parts that were implemented in the final solution of Re:Load were tested during the project together with a 1:1 scale physical mock-up of Re:Volt, but no full scale prototype was created or tested. Hence, it can not be fully validated that the product would work as well in practice as it can be seen to be in theory. A continuation of the project would then be to produce a functioning full scale model of Re:Load, to test, evaluate and develop further. Another aspect that would need

to be verified is the cooling capability of the final solution for Re:Volt and the cargo space of Re:Volt. With a special focus put on operations in more challenging conditions, such as high outdoor temperatures and multiple door openings within a set time frame. Future development would also entail looking into the feasibility and different aspects of manufacturing and production of the solution.

Something that would also need to be further developed is design elements that have been of lower priority in this thesis project, such as for example the transportation dolly used. One aspect related to this is for example the fastening of the transportation dolly to the cargo space during inserting and removal of the shelf unit from the cargo space.

Another area to investigate further would be to look at the different use cases identified as relevant for Re:Load part of Re:Volt, compared to other delivery alternatives. For example what kind of operations would benefit from a switch to using Re:Load part of Re:Volt as one of the delivery vehicles used, from an ecological, user or an economical perspective. Taking aspects such as loading capacity, adjustability of the physical structure of the shelf solution, easy access to goods and thermal energy retention into account. These areas could hence be further investigated.

# 8

## Conclusion

A variant of the cargo space of Re:Volt was designed, including additional physical structures to support the goal of the thesis project. The goal being to enable a sustainable, user friendly, adjustable and efficient alternative for last mile delivery, as part of urban transportation of groceries covering dry, refrigerated and frozen goods, using the electric vehicle Re:Volt. The end result was an implemented cooling solution and a shelf unit designed for the cargo space of Clean Motion's electric vehicle Re:Volt, to facilitate its use for transportation of groceries during last mile deliveries in an urban environment.

The working environment for couriers was intended to be improved, by contributing to a better working situation in comparison to current solutions seen in the industry of last mile delivery of groceries in regards to physical- and cognitive ergonomics. Another aim was to make a solution easy to implement for relevant companies within the industry of last mile delivery of groceries, utilizing off-the-shelf solutions when suitable as well as taking current working processes and needs into consideration. Finally, it would benefit the end customers if a high product quality could be ensured, implementing an unbroken cold chain and by having orders secured separately within the vehicle. Supporting the physical integrity of products and prevent groceries part of orders from getting mixed up or being put under excessive pressure.

The final solution Re:Load ensured that couriers would have access to all grocery bags, whilst maintaining a good, non-harmful working position relative to physical- and cognitive ergonomics. The combination of the implemented cooling system Dometic Frigo DC2500 and freezer space utilizing iFoodbag alvoboxes made it possible to guarantee an unbroken cold chain, potentially desirable for both the company operating the last mile delivery and the end customer receiving a delivery. Generally resulting in a lower impact on the food product quality part of the last mile delivery. Re:Load was designed to be a product feasible to produce and manufacture, with simple geometries, materials and existing solutions such as insulation panels and telescopic rails used. This further supported the intentions to create a solution easy to implement into different operations within the industry of last mile delivery. The final solution Re:Load and the cargo space of Re:Volt also strived to ensure a limited amount of thermal energy loss as part of the delivery.

The shelf solution together with the rest of the cargo space design was considered successful, meeting all requirements set. The solution was found to generally answer to identified needs of operations within the last mile delivery of groceries, and was

deemed suitable to be used for either quick commerce or planned delivery applications. It could also result in the potential to shape and establish a new market segment for the food delivery industry where the gap between operations of quick commerce and planned deliveries would decrease. Alternatively, the vehicle could operate within the two areas of quick commerce and planned deliveries simultaneously, but its implementation for planned deliveries would require some adjustment compared to the current structure and order of priorities.

Even though the project was deemed successful, there are many areas that could be further investigated. No full scale, final prototype was made or tested in any of the intended use cases related to the user situation when interacting with Re:Load, nor the cooling capabilities of the cargo space. This was considered necessary to fully evaluate and validate the product. Another area to investigate further would be to look at the different use cases identified as relevant for Re:Load and Re:Volt, compared to other delivery alternatives. For example what kind of operations would benefit from a switch to using Re:Load and Re:Volt as one of the delivery vehicles used, from an ecological, user or an economical perspective. These areas are some examples of what could be further investigated.

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## APPENDICES

A

Interviews

## A.1 Interview Answers from E-Commerce Transport Manager

The interview resulted in the following takeaways:

The interviewee had good insight into the operation, currently using a larger light duty truck using HVO fuel with an active cooling system covering half the cargo space. The interviewee was generally positive to using electric vehicles, if it could offer similar or more capacity than vehicles currently used.

### *Capacity of the cargo space*

The cargo capacity of vehicles in use were separated into two spaces. There, 50% of the cargo space was cooled to what was estimated to be a temperature of 2–4 °C, and 50% was insulated with the option to regulate the temperature if needed. The cooled space was used for refrigerated and frozen groceries, and the insulated space for dry and temperature sensitive groceries such as vegetables.

### *The setup of loading and delivering goods*

These steps were said to be done manually, without breaking the cold chain. Each customer gets the food delivered in a paper bag. The bag is placed in a plastic box, with a maximum of three bags in each box. Several orders could not be mixed in the same box. Each box was placed in a frame that could hold a maximum of 20 boxes. A vehicle had a capacity of four frames, two in the cooled area and two in the insulated area thus resulting in a total capacity of 80 boxes or a maximum of 240 bags. The heaviest point of loading the goods was when placing the full boxes in the frames. Each box had a maximum weight of 20–25 kg.

The fill rate of the vehicle varied. The vehicle had a designated area for doing its delivery rounds in, and how full the cargo space was for a run depended on the orders customers in that area made. There was a system calculating how the routes should be set up, with the intention to fill the vehicles as much as possible. Some vehicles were fully filled.

### *Temperature regulating techniques*

The cooled area was pre-chilled using power from the grid. All boxes used in the cooled area were insulated. Refrigerated and frozen goods were separated into red respectively blue boxes. A compressor refrigeration unit was used in the cooled area. Dry-ice was placed in a net in the lid of blue boxes to create a temperature suitable for frozen goods. The dry-ice was manually placed in the lid of these boxes. The interviewee was not sure why dry-ice was chosen to be used to create temperatures low enough to be suitable for frozen goods, but it was believed to be connected to the structure of how the groceries are handled and loaded onto the vehicle prior to the delivery run.

There was an additional unit placed in the insulated area that is to regulate the temperature if it got too hot or cold in the cargo space, affected by the outdoor

temperature. The approved temperature range with both an upper and lower air temperature was believed to be regulated, but no exact numbers could be given by the interviewee. According to the interviewee, there was no additional efforts made to ensure the product quality for more temperature sensitive products such as fruit and vegetables.

#### *Unloading of goods*

The vehicle was used to deliver each order separately to end customers. The boxes were generally not to be removed from the vehicle. Instead the courier was carrying the paper bags part of the order by hand to the customer. If the last part of the delivery outside of the vehicle was longer, the box could be used in combination with a hand truck available in the vehicle. This hand truck was fastened either on the wall of the cargo space, or by the passenger seat in the cabin (if the seat had been removed).

A box that has been outside of the vehicle, or being placed on the floor of the cargo space during unloading was never supposed to be placed back in the frame in a way that it could contaminate groceries placed in the boxes below. In addition to this, the interviewee said that all boxes had a lid, and that it should be possible to reach all boxes to unload the paper bags, without fully taking the box out of the frame. The unloading process was described by the interviewee as dragging out the box, taking off the lid to the box, taking out the paper bags, putting the lid back on and then pushing the box into place again.

#### *Delivery runs*

It was estimated by the interviewee that an average of 20–25 orders can fit into the vehicle for one delivery run. In an area with a high density of customers the driving time was generally lower. It was estimated by the interviewee that these delivery runs were a maximum of six hours for the total run from and to the logistics center. This was used as a motivation that the interviewee would prefer an electric vehicle with double the cargo capacity in order to be able to carry more customer orders. The total weight of the vehicle was estimated by the interviewee to be around 1000kg.

A general time frame of 6–8 hours was given, corresponding to a total distance of 100-150 km per delivery run. Depending on the time of year and the buying patterns of customers, the limiting factor was either the total weight of cargo or the space for bags within the cargo space.

#### *Temperature monitoring*

The air temperature in both the chilled as well as the insulated space was continuously monitored using thermometers being installed in the space. In addition, portable stick thermometers were used to measure the product temperature by measuring in between goods. This was an ISO-requirement, according to the interviewee. These thermometers were connected to systems that both the driver and the transportation management could follow or follow up on. The portable thermometer should be kept outside of the cooled area when not in use.

### *Requirements of the different temperature zones*

The share of the cargo space that was used for transporting frozen goods follows the pattern of customer orders. This percentage was not given, but was generally stable according to the interviewee. The share was decided by the logistic system called Ocado that was used to plan the deliveries. There were always some groceries part of a delivery run being frozen.

### *Cleaning of the space*

When empty, the cargo space was a fully open space, being cleaned using a high-pressure cleaner. The cargo space of delivery vehicles were cleaned and controlled every day, and the level of cleaning was regulated by the condition of the space.

There were some more simple cleaning supplies available in each delivery vehicle, to be used for some light cleaning if something was spilled during the delivery run. This was kept in a cabinet in the vehicle. In addition, a trash bin was also available.

## **A.2 Interview Answers from E-Commerce Transport Manager Dagab**

The interview resulted in the following takeaways:

Dagab Inköp & Logistik AB is a large distribution concern within the food sector, active all over Sweden. E-commerce was said to be focused on Stockholm and Gothenburg, but available in other parts of Sweden as well. Willys, City Gross, Hemköp and Snabbgross were all companies covered within the logistics which Dagab was responsible for.

The vehicles used were introduced as larger heavy duty trucks with a trailer as well as smaller C-classed vehicles in general and smaller light duty trucks of up to 3.5 tonnes. The larger trucks were mainly used for deliveries to stores. The smaller vehicles were generally the ones used for home delivery of groceries.

### *Example standard order*

An example standard order from Willys was given of 1000 SEK, estimated to weigh 35 kg.

An order usually consisted of all types of goods: colonial, refrigerated and frozen. The share of colonial produce was estimated to be 60% of the total cargo volume. An estimation of 30% of the cargo volume being refrigerated and 10% being frozen was given by the interviewee.

The proposed average order size of 6+-2 paper bags given by the interviewer was seen as reasonable, but no exact range were given. The number of paper bags varied depending on the type of goods. A point was made by the interviewee that the driver delivering the order should be considered, through keeping each paper bag a

manageable size.

#### *Temperature zones*

The cargo space was cooled to a temperature of 2°C–4°C. A top-loaded freezer box of -24°C was available in the cargo space. An active cooling system in the form of a freezer box was said to be chosen over other materials potentially causing harm to the driver if mishandled, such as dry-ice. The interviewee was emphasizing to keep the work environment of the driver in mind when choosing the cooling method. No ‘non-cooled’ zone were available in the cargo space.

To preserve the product quality, the product temperature of colonial produce might need to be regulated. Chocolate never risking to be melted during delivery was given as an example.

#### *The setup of loading and delivering goods*

The cold chain was presented as kept intact from packing the groceries in bags to being delivered from the vehicle. All types of products, including frozen goods, were packed into paper bags. The steps taken were products being placed into paper bags, to then being stored in an area called the staging area where the orders were packed ready and stored until loading, to then be loaded into the correct delivery vehicle. The user responsible for loading goods onto the vehicle has the delivery order as support. There was no risk of uneven loading of goods in smaller vehicles used for home delivery (light duty trucks with a total weight of up to 3.5 tonnes). During the time products were in the staging area, loaded and throughout the delivery run in the truck the temperature for refrigerated and colonial goods was given to be 2°C–4°C. The general aim was to always opt towards a slightly lower rather than higher temperature according to the interviewee.

The limiting factor when filling the cargo space of the vehicle used for home deliveries was said to be the cargo weight. The weight limit for cargo on a light duty truck was set to 1000kg, a weight that was easily reached when delivering groceries, according to the interviewee.

#### *Structuring of goods and orders*

The interviewee had a wide area of responsibility and could not give detailed examples of how the orders were packed and structured into the delivery vehicle. It was said that the method varied depending on the geographical location and the respective conditions for that particular space and organization. The loading method used was also said to be dependent on the way the delivery was structured, in order to avoid situations where orders have to be restructured to get access to particular cargo. This work was mainly done at the staging stage of the loading process.

More general examples for how orders were placed into the delivery vehicle for delivery were given as using cages, shelves, putting orders on the floor, using boxes and other similar solutions. The interviewee gave the example that rollable cages were tried for a period of time, but seen as taking up too much space.

The interviewee could not answer to what exact tools were available to use during loading of the vehicle, but tools offering rolling assist in different forms were said to be available.

### *The delivery*

The interviewee saw the preferred method of loading goods into the delivery vehicle as closely connected to the method of unloading cargo. As well as how the end-consumer wants the order delivered. An example is given that an order might need to go to the fifth floor in a building in Stockholm. Here it could be an issue to find available parking for the delivery vehicle in connection to the delivery address.

### *Possible improvements of work environment for users part of the home delivery*

The interviewee thought that the use of plastic boxes could make the work easier, but the end-customer would not want to receive a plastic box.

Another concern raised around the preferred delivery format to the end-customer was regarding using a cardboard box for delivery. Mainly based on what was said by the interviewee to be the undesirable amount of trash generated from the packaging part of receiving a delivery of groceries.

### *Cleaning*

The cargo space was cleaned internally daily.

### *Use case with Re:Volt*

The vehicle size of Re:Volt was considered as very small in comparison to currently used vehicles by the interviewee. Remarks were made around the available cargo volume when order sizes are in the range of 6–8 paper bags each related to the manpower required in drivers. The interviewee saw the standard order from E-commerce through Dagab as more of a weekly grocery shopping, with larger order sizes.

### *Heavy duty trucks*

The larger trucks used were divided into temperature zones of refrigerated goods and frozen goods on the truck and colonial produce on the trailer. The divider between the refrigerated frozen area was said to be a movable transverse wall in order to adapt the spaces to the cargo volumes transported. This wall was manually moved and put in place by tightening supports.

## **A.3 Interview Answers from Bzzt**

The interview resulted in the following takeaways:

### *Vehicle handling*

The interviewee's view was that vehicles are generally not handled very carefully by drivers. Relating this to the vehicle Zbee, it was said to be able to take some beating and that that was needed. People were said to drive hard and that the vehicle could

be unstable. The issue with accidentally hitting curbs and the impact felt in the vehicle was voiced by the interviewee.

It was seen as a hassle and not optimal to have to manually lock and unlock the vehicle with a key when leaving or coming back to it. The cargo space itself can be left unattended, but has never experienced food being stolen.

Speed was seen as important to the interviewee, both when it came to the speed (km/h) of the vehicles and the times it takes to park and lock (and other tasks that can slow you down). It was seen as positive that Zbee was smaller and could fit to park practically anywhere.

In a cargo vehicle with this kind of smaller cargo space the main area of concern/-focus according to the interviewee was the driving experience, with the interaction with the actual cargo space having a lower priority, as long as there was a simple open space for it.

#### *Cargo handling*

The interviewee saw it as beneficial to have the food being easily secured. At the moment sometimes it is done by wedging it between the seats or using the seat-belts available. Some hooks and bungee cords or use of nets were voiced as preferred/-possible solutions.

The courier placed bags where there was space, on the passenger seats or on the floor by the steering wheel. The interviewee considered it obvious that the space was not made for the purpose of delivering food.

Another issue voiced by the interviewee was how the compartment for packages was not always easily accessed in a smooth way. For example requiring the opening of a door and zipper to access cargo through the passenger door in the vehicle Zbee.

## **A.4 First Interview with a Development Engineer at Dometic**

The interview resulted in the following insights:

#### *Insulation*

Pre-made PUR (polyurethane) wall panels were considered by the interviewee to be a good choice for this type of implementation. It was described as a rigid foam with a layer of aluminum on both sides in order to keep insulating gas within the material. Polyurethane had higher insulation properties than styrofoam, and was the standard since it takes up less volume. Calculations for necessary insulation thickness and static energy loss had to be made. All walls, roof, floor and other sides of the cooled part of the cargo space have to be insulated. Without any thermal

bridges, such as metal beams part of the vehicle frame, that could increase the passive thermal energy loss. The non-cooled area might get away with using a slightly less thick insulation layer. It was also said as important to know the temperatures that Re:Volt was supposed to operate in.

### *Cooling solution: Dometic FrigoDC2500*

It was recommended by the interviewee to choose an active cooling system such as Frigo DC2500. Then the evaporator unit releasing the cold air will most likely be placed in the roof all the way closest to the driver's space. The part had the dimensions of 66x50x16 cm. The compressor and condenser unit would have to be installed outside of the cooled space with satisfactory air flow for cooling purposes. The most likely placement is in the chassis of the vehicle. The total weight of the system weighed 43 kg and had a capacity of cooling a volume up to 5 m<sup>3</sup> at 0°C. Moreover, it had a fan included in the evaporator unit placed in roof. Something needed for the air circulation in the cooled space.

The cooling part of FrigoDC2500 has to be fastened in the roof, and not in the insulation. Thus, a hole has to be made in the insulation plate. Most parts can be installed from the start, without a specially certified technician. This is later needed for some of the installation of the cooling system.

### *Competitive advantage*

Having no need for moving around ice packs and similar is seen as beneficial by the interviewee. A removal of the need of handling dry-ice to create frozen temperatures is also seen as positive.

### *Air circulation*

The use of a shelf system will benefit the air circulation around each delivery box. The interviewee sees it as less crucial to have a high air flow around the cargo when the cargo is already cooled before it enters the vehicle.

### *Doors and internal walls*

All doors are seen as weak points. Not only when they are opened and let warm air in but the cold can also more easily seep out through the seals around doors. The doors' insulation were also usually not as thick as the surrounding walls. This is also the case for all moving parts, which can be good to skip according to the interviewee. It was still not seen as an impossibility to implement moving parts such as walls, with the comment from the interviewee that the need for moving would have to be justified. If it was to save energy there is a risk that it might result in losing more energy by not having the wall stationary. It was important to build a functional vehicle. It was usually possible to build around the need, for example for several doors. Another important point was to consider if any walls need to have some structural integrity and strength. The seals are an important area in order to limit energy loss because of doors. Either pressed tight by some manual locking solution or using magnets like refrigerators do.

*A need for a freezer space*

Pre-made food bag deliveries might not include frozen food, so giving that option to delivery companies might not be necessary if they do not have the need to deliver frozen food. If a frozen space is wanted in the vehicle, a second freezer unit would be needed. It was seen as possible by the interviewee to make a second cooled area using a second compressor to create this freezer space. If the space needed for frozen goods is smaller it could have a freezer box instead of a second unit for the freezer. However, it is ultimately seen as beneficial to avoid a freezer compartment fully. This was mainly based on the added complexity of having another cooling system installed or in other ways added.

*Eutectic plates in relation to a freezer space*

Phase change materials were mentioned to be used to keep the temperature in a space stable, being energy dense. They were seen as being quite heavy, using a salt mix inside them. It could be relevant to consider that there will be a loss of energy when using a compressor to cool the PCM instead of just cooling the space itself. It will, according to the interviewee, never be worth it to have a freezing solution using stationary eutectic plates in the vehicle. In that case, it is seen as better to use a second freezer unit to cool the air since the same electric elements are needed.

## A.5 Second Interview with a Development Engineer at Dometic

The interview resulted in the following insights:

*The cooling system*

The interviewee was of the strong opinion that having a single active cooling system always was preferred. Adding additional ones also add unnecessary complexity. It was said that it was possible to connect cooling systems in parallel, and thus increase the cooling capacity linearly. It was proposed as an idea to the cooling expert to utilize four smaller cooling units in order to increase the cooled volume through a higher cooling capacity. The reaction to this from the expert was that four cooling units are seen as a lot, especially implemented in such a small vehicle as Re:Volt. Resulting in a more troublesome installation process, as well as more points of failure with the increased complexity. Contact information was given to another expert to further discuss cooling unit alternatives.

Defrosting was raised as important for an optimal operation of the cooling unit(s), and has to be automated as part of the cooling system.

Related to the uncooled space potentially having a need for temperature regulation when operating at extreme outdoor temperatures, heating solutions were discussed. The interviewee saw that adding heat to a space as an easier solution than covering the need for cooling. Another available solution for temperature regulation, switch-

ing from cooling to heating and vice versa, was introduced as adding a 3-way valve. Still, this addition was seen as unsuited for smaller applications such as the cargo space of Re:Volt, more intended for ACs in campervans and similar.

An observation was made of the implementation of a channel for additional air flow as part of a wall in order to reach a satisfactory circulation of cold air. The interviewee did not think that that kind of addition to the cooled area of the cargo space of Re:Volt would be necessary.

### *Some alternative cooling systems*

The alternative cooling unit of utilizing an AC for camper vans was physically looked at and discussed. Despite being an AC, intended for creating higher temperatures than refrigeration, the over dimension of it for the cargo space would in theory result in a low enough temperature for refrigerated goods, according to the interviewee. The unit was large and needed a direct passage to the space it was supposed to cool for both in and outgoing air. The placement of the unit was discussed, under the driver's seat being the only feasible option. After some discussion, this product was decided to not be further investigated as an alternative, based on the size, air flow requirements, modifications needed of the physical space of Re:Volt as well as its intended use not being the one needed for the cargo space of Re:Volt.

Questions related to some marine cooling unit applications were inquired as part of available alternatives of cooling systems. More specifically the compressor called ColdMachine CU-96, the refrigeration evaporator Dometic ColdMachine VD-14N and the freezer evaporator Dometic ColdMachine VD-16. The interviewee did not have direct experience or knowledge about the implementation of these.

### *Insulation*

A general guideline given by the interviewee was that it is better to use thinner insulation panels than using inlays in the insulation panels. Based in this resulting in, among other things, added complexity of production and decreased insulation properties. According to the expert, not all insulation panels have to be the same thickness, sometimes a thinner panel can be seen as acceptable and motivated or compensated for by making other insulation panels a bit thicker. The expert claimed that 50 mm insulation panel thickness as generally being thick enough when being on the safe side. and 30 mm insulation panel thickness was usually sufficient, but can be seen as being on the lower side in some cases. Another thought raised by the expert related to ease of production is that it will be highly preferred to enable keeping the edges of insulation panels straight.

The product Dometic Delibox was discussed. The box had a shelf that separated the space into two compartments, one hot and one cold. An observation, also being confirmed by the cooling expert, was that this shelf does not have any seals. The shelf plate itself was insulating, but instead of a seal around the edges to keep the temperature zones intact, the shelf was just held in place by having the edges inserted around 1.5 cm in horizontal grooves on the side walls. This was seen as

enough sealing between the hot and cold compartment, according to the expert interviewed.

#### *Cooling capacity*

The unit for cooling capacity is watt (W). The cooling capacity is a factor that could be used to compare different cooling units through their ability to cool a certain volume, assuming other factors that affect the thermal energy loss are kept static. The cooling capacity was also used to ensure that the space that was kept cooled to a satisfactory temperature. This is done by comparing the cooling capacity of some cooling unit to the sum of the passive thermal energy loss through the insulation and the active energy loss when the space is opened resulting in warmer air replacing the cooled air inside. The expert said that the cooling capacity of cooling units were generally slightly better than what is stated in their documentation.

To gain insight into the product development process as well as to support the questions asked to the cooling expert, the facility, cooling lab and some of the company's cooling products were viewed.

## **A.6 Interview with an Operations Manager at Pic-smart**

Additional details mentioned during the interview:

A vehicle called Inzile was said to be the main vehicle used for deliveries. This vehicle does not have any active cooling capability, meaning that the paper bags packed with groceries were currently not stored in any cold compartment during delivery. The frozen goods were said to be packaged in an insulated paper bag of 11 litre called iFoodbag, with a freezer pack inside. These were given out to the customers at delivery, resulting in a loss of about 9 SEK per order related to the packaging method of frozen goods. On average, 0.6 iFoodbags and 3.6 paper bags were used per order. It was voiced by the operations manager that an aim of Picsmart was to go towards a more circular system, based in economical and sustainability aspects. The vehicle Inzile was said to be quite tall and the top shelves were seldom utilized. Additionally, the size and large upwards pivoting doors of Inzile were at times said to pose an issue when trying to find a parking spot and opening the cargo space in certain traffic situations.

## **A.7 Interview with a Company Representative from iFoodbag**

The interview resulted in the following insights:

#### *Additional information about the ifoodbag*

The bag was available in three sizes intended for use when transporting cooled gro-

eries: 11 L, 15 L and 25 L. The gel pack used with the ifoodbag was said to have cost of around 30 SEK. The company representative believed this could be seen as relatively expensive to give away with each order in an operation of regular home delivery of groceries. Delivery of more expensive and sensitive products such as meat and fish deliveries were seen as an area where that expense could be more motivated, where the packaging could be seen as an investment. Some stores being customers of the ifoodbag have been seen to implement both bags and gel packs into a return flow being more circular, where the driver collects the bags after use. This is highlighted as the most sustainable way to use the bag, even if it is made out of 100% paper and possible to recycle. One remark made regarding this was that the customer experience should not be affected by the reuse of bags and that it is important that the bags being reused are in good condition.

### *Additional information about the alvobox*

The alvobox is available in two sizes: 51 liters and 151 liters, where the larger box can hold three normal paper grocery bags at once, and the smaller box three smaller ones. The boxes are adapted to fit on euro pallets, four large boxes on a standard pallet, and two boxes on a half pallet. The larger alvobox weigh about two kg and the smaller alvobox weigh about one kg. The PCM block used for freezer temperatures of below  $-21^{\circ}\text{C}$  weigh 4.1 kg. The interviewee agreed that the use of this type of box to keep products frozen for the intended time span of 2–3 hours was preferred over the insulated bag, and kindly provided the project with both the larger and the smaller alvobox for user tests and evaluations.

It was discussed how customizable the alvobox was. This covered aspects such as add-ons related to ease of use like mounting handles to the sides of the box and hinges to edges as well as for example the wall geometry. It was stated that external handles could be added to any box very simply by screwing them into the sides of the boxes, but that handles that would result in a change of the boxes geometry would require a large batch order to make it an economically viable change to the product.

### *Challenges of keeping an intact cold chain*

The iFoodbag representative argued that some larger companies within the sector of E-commerce of groceries, using a refrigerated truck in the weight class up to 3.5 tonne have a difficult time fulfilling the food safety regulations in more extreme outdoor temperatures. The example was given of a day with a temperature outside of  $30^{\circ}\text{C}$  with many delivery stops close in time to each other. Since the active cooling unit has to be turned off during unloading when the cooled cargo space is open, sometimes resulting in the entire rear being opened to access the cargo, a lot of the cold air is lost and potentially not fully replaced quick enough to not affect the air and product temperature of goods. Insulated boxes are said to potentially support solving that issue.

# B

## Discussions Regarding Cooling and Freezing Technology

## B.1 Cooling Technology Alternatives

### **Alternative: Dometic Frigo DC2500**

Frigo DC2500, 2.3.4.1, has been found to be able to guarantee a coverage of the cooling requirements for the full cargo space, even with a number of door openings part of a delivery per hour. This enables a large flexibility in the way the vehicle is possible to use. With Frigo DC2500 being an active cooling system, it will continue to be operational and provide the same level of cooling as long as the battery of the vehicle overall has capacity left, see section 2.3.2.1.

It is estimated based on the air flow rate of the cooling system that the time to restore a temperature of 2°C–4°C would take a maximum of a few minutes, see section 2.3.4.1. It is also seen as a complete product, with one installation needed. This includes additional features such as an external display to monitor the temperature in the cargo space from the driver's cabin.

A challenging aspect of utilizing Frigo DC2500 is how it is an active cooling system requiring power supplied from the battery in order to keep functioning. This can be seen in the case covering the power consumption of the cooling system in a more strained but still realistic use situation, see section 2.3.4.1. This was discussed with a relevant person at Clean Motion. Resulting in a reservation around this as being straining on the battery capacity, but still viewing Frigo DC2500 as a feasible cooling system to implement and utilize.

### **Alternative: Dometic ColdMachine**

ColdMachine VD-14N is the suitable evaporator to use in combination with the compressor CU-96 to create a cooling system for temperatures of 2°C–4°C. This cooling system has a maximum capacity of 300 litres, see section 2.3.4.2. This is a lot less than the full cargo space and also lower than the identified need regarding the volume of the cooled space, see section 4.1.7.1.

As discussed with the development engineer with cooling technology expertise, see section 4.1.6.3, the cooling volume when using a cooling system with the CU-96 compressor and suitable evaporator can be linearly increased by using several cooling systems. In this dialogue this is strongly advised against based in the added complexity, mainly affecting the difficulty of the installation and how vulnerable the system is for failure during use.

ColdMachine as a cooling system is a combination of several separate units that together build up the complete system, see section 2.3.4.2. This means that it is not a complete product, and no additional functionality or features are included. ColdMachine is an active cooling system and would provide the same level of cooling throughout its use, as long as the battery of Re:Volt has capacity.

### **Alternative: Active eutectic plate**

The information around the use of eutectic plates as part of a cooling system was

found to be limited, see section 2.3.3.2. No direct observation of the use of eutectic plates in delivery vehicles as part of the user or market study has been made (see section 4.1.4 and section 4.1.5). Some aspects could still be addressed for this alternative.

Eutectic plates are seen as a passive cooling system, resulting in no straining on the battery during the use, see section 2.3.3.2. The plates are also able to cool a space even when they go above their desired temperature (of e.g. 2°C–4°C), but to a lesser degree the longer time goes on. They can however not be "turned off" when a door is opened.

The time the cooling system can keep a satisfactory temperature in the cargo space during delivery has been seen to be around 11 hours in a specific case where it is assumed that no openings of the space was made. After this, the eutectic plate need to be refrozen for 10–12 hours, as described in section 2.3.3.2. During this time, the eutectic plate stay in the cargo space while being connected to an external compressor unit. Making the delivery vehicle unable to use during this time.

An aspect to consider in utilizing eutectic plates is the time it takes for the temperature to recover to a cold enough level according to food transport regulations after a door opening has been made. An estimate of 30 minutes recovery time has been made from data in the form of a graph provided by an eutectic plate company, see section 2.3.3.2. The weight range of eutectic plates is found to be 25–88 kg, where the higher part of this range was seen as relatively high in comparison to the total weight of Re:Volt.

An example of an eutectic plate product physically fitting to be mounted in the roof inside the cargo space, see section 2.3.3.2 weigh 40 kg and have an energy extraction rate per plate of 1710 Wh per plate. Due to the lack of information, this has not been possible to be fully compared to the cooling capacity of an active cooling system. Another result of this is not being able to confirm that the cooling capabilities will cover the requirements of the targeted use case.

### **Alternative: Passive PCM**

PCM is seen as a cooling technique utilizing PCM blocks filled with a solution absorbing energy during the phase-change from solid to liquid, see section 2.3.3.1. These blocks are then placed in insulated boxes of an average volume of 50 L, see section 2.3.3.1. This was seen as a small cooling volume relative to the full cargo volume, equating to about 2.5% of the available cargo space. In addition to this, each insulated box take up additional volume with the insulation around the available cooled space in each box, see section 2.3.3.1. The insulated box was generally found to be top-loaded, resulting in added steps in the process to access goods within the cooled space. Part of this was also how the use of PCM blocks in insulated boxes was found to be a cooling solution with a low level of flexibility in how it is used as part of a delivery process. The use of PCM as a cooling system also adds additional steps of required manual handling in that the PCM block needs to be transferred between

the insulated box and some kind of freezer in order to change back to a solid, frozen state and thus restore its cooling capabilities, see section 2.3.3.1. PCM as a cooling technique will stay operational at a satisfactory temperature for a limited time. The PCM block used for cooling does not stay in the vehicle during the freezing of PCM blocks to reset the cooling capabilities. This has been seen to enable the use of several sets of PCM blocks in order to reduce the waiting time between uses of the vehicle with a functional cooling system.

## B.2 Freezer Alternatives

An aim of the second ideation phase was to create an integrated solution for all functions when the vehicle and solution is to be sold, without requiring a customer to be overly relying on external suppliers to keep some functions fulfilled. This includes elements part of the solution used to fulfill functions related to cooling. The importance and strive for a more circular system was further supported in direct contact with an operations manager at a company operating within the market of the intended use case for Re:Volt with the solution implemented, see section 5.1.1.1. The passive freezer alternative chosen to implement was a passive PCM product from iFoodbag called alvobox, see section 5.1.2.4. The product consists of an insulated box of 51 liters in the material EPP used in combination with a PCM block intended for products to be kept at a temperature of below  $-21^{\circ}\text{C}$ . This solution was seen as suitable related to the capacity identified as needed, see section 4.1.7.1. The volume need for a freezer space varied but was seen to be around 10 % of the total order capacity. By implementing the alvobox, the freezer volume was seen to be flexible from zero to four 51 liters boxes per delivery round. The smaller alvobox of 51 liters was chosen over the larger alvobox of 151 liters after both boxes were tested together with a 1:1 scale mock-up of Re:Volt, see section 5.2.2.



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