MA4-ID13 ID LONG MASTER THESIS PROJECT AALBORG UNIVERSITY JUNE 2012

# FLUX

TOOL CARRIER CONCEPT

## PROCESS REPORT

# Summary

This master thesis deals with the design of a new tool carrier solution for the company VPM Maskiner A/S.

The Flux concept challenges habitual thinking in an otherwise neglected industry through user-driven innovation, and introduces a new type of steering with a hybrid power train system. Said system allows for the creation of a platform that is both space saving and more agile than conventional tool carriers. This thesis works with an integrated approach to complex product design, moving between system level and component level. Utilising an electric on-board infrastructure, the concept expands on future upgradeability through technological innovations in energy efficient propulsion to meet with the societal tendencies.

VPM Maskiner A/S is presented with a design solutions that challenges the tool carrier industry on value, and takes a bold new approach to define how the tool carrier should be conceived as an entity in professional maintenance equipment.

# Preface

**Industrial design specialisation**
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**Project Title**
Flux

**Project Period**
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**Supervisor**
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and Media Technology.

**On DVD**
E-drawing
Technical drawings
Digital reports
Appendices
Datasheets
Brochures
Relevant web page captures

## ACKNOWLEDGEMENTS

During this long master thesis, spanning almost two semesters, the design team has had the opportunity to converse and confer with many different professionals, and would like to thank appropriately, especially;

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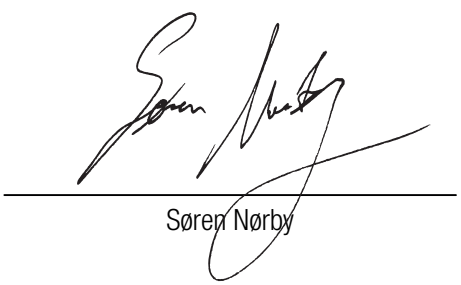
Louis B. Danielsen, CEO of VPM Development, for his day-to-day support, astute advice, and interest.

Stig Møller, Chief Sales Representative, VPM Maskiner A/S, for his keen engagement, insight, and honesty.

And finally,
Finn Schou, Primary Supervisor, for his interest, guidance and extraordinary dedication.

Thank you.

Design team



Søren Nørby

Malte Aarup Eriksen

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Final product presentation is produced in accompanying product report.

# INTRODUCTION

This section talks about the setting in which the thesis has taken place, the collaborative partner, the circumstances of the cooperation, and the project schedule.

# Company background

This thesis is centred around a cooperation with a small company, producing "tool carriers" for professional outdoor upkeep. VPM Maskiner A/S (henceforth referred to as VPM-M), is a small workshop of 16 employees situated in Stauning, Denmark. An excerpt from their website:

Henrik Christiansen
CEO of VPM-M

Frank Christiansen
Idea guy

John Christiansen
Responsible for economy

*"VPM Machines was founded in 2005 in Stauning by 3 brothers: Frank, Henrik and John Christiansen. They all have extensive experience in development, production and servicing.*

*The employees at VPM Maskiner are characterized by commitment and good old "west-jutlandish" stubbornness - things are supposed to work. So there is plenty of experience, creativity and ingenuity to develop solutions for all outdoor maintenance - which must be effective and with a high degree of comfort.*

*The users are always the starting point for new product development within VPM. In developing the VPM 3400, users have been involved throughout the process - from drawing to test - to ensure that the requirements of those who will use it in everyday life are being met.*

*Openness and constructive dialogue characterizes us. We constantly challenging each other in search of new ideas and improvements that benefit the customers.*

*We also focus on protecting the natural environment as much as possible and strive for a high recycling rate in our products.*

*At the same time we want a good working environment, in which we respect each other and recognize that people are different. Humor and a twinkle in the eye gives energy in order to create effective solutions to customers."*

*[vpm.dk, 2011]*

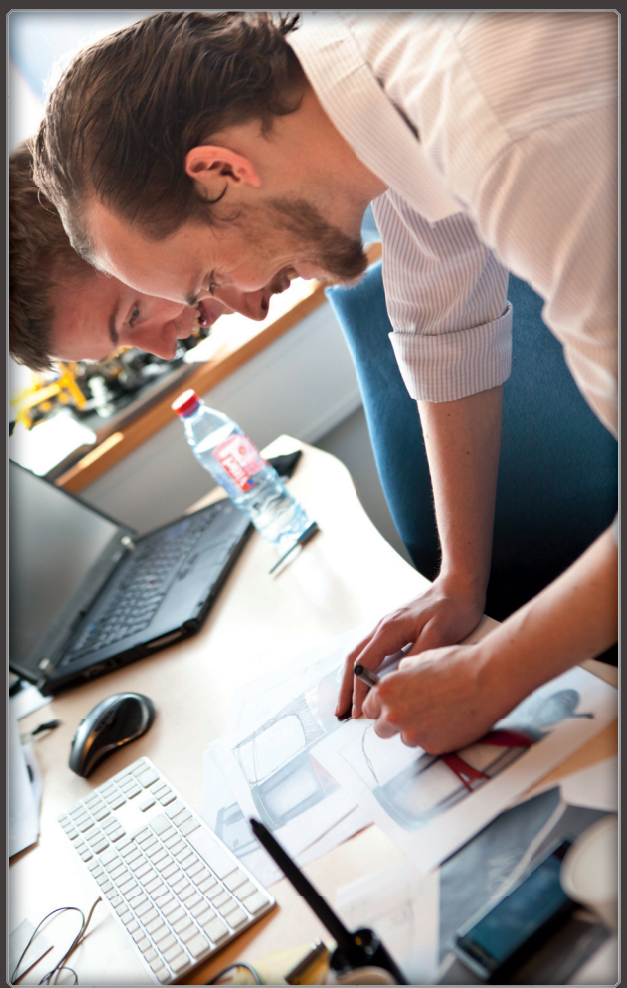
The founding brothers all have a background in construction and maintenance of agricultural machines, which shows in the approach utilized in product development – sturdy equipment engineered to withstand very rugged use.

The company VPM-M has been kick-started through Innovation MidtVest A/S, a company that facilitates the process of creating a company from an idea, with the specific goal of challenging the industry giant Nilfisk-Egholm. Innovation MidtVest has also started VPM Development ApS based in Aarhus, Denmark, (henceforth referred to as VPM-D) to develop an all-electric and otherwise identical edition of the VPM tool carrier. VPM-M and VPM-D have no legal relations, but are connected through investors.

# The office

The design team has had the distinct fortune of a dedicated office with VPM-D in Aarhus throughout the project period. This has contributed a sense of employment through daily contact with VPM-D staff, and the team gained a keen insight into a newly started company. This has also had the consequence of enabling the team to discuss and resolve questions directly and quickly with the companies.

During the design team's stay in the office at VPM-D in Aarhus, and on visits to VPM-M in Stauning, many short conversations (often related to concurrent work) have taken place that has enlightened the team and provided data for research, concept development, and detailing phases.



VPM-D CEO Louis Billesøe Danielsen (foreground)

VPM-M Sales Representative Stig Møller (left)

VPM Electro developer Bjarne Wind (background)

# Internship converted

The cooperation with VPM-M and VPM-D started with an internship period, which was later converted to a long master thesis. The internship period focused on developing tools for the VPM tool carrier, specifically two snow ploughs.

When the design team was introduced to the company in Stauning, there was a clear sense of distance between the employees and the team, seemingly stemming from the "fancy" nature of university students.

The internship period provided the fortunate opportunity for the team to engage in both technical drawing, welding, grinding, and testing in Stauning, which - to some degree at least – has broken that initial barrier.

Design team assembling and welding a prototype snow plough in Stauning

When VPM-M CEO Henrik Christiansen enquired about a redesign of the cabin, the opportunity of converting to a master thesis arose. The initial outline from Louis B. Danielsen (VPM-D CEO) and Henrik Christiansen, was to redesign the cabin, improve ergonomics and aesthetics – basically "make it better".


VPM-M CEO Henrik Christiansen testing the new plough

The internship period provided the design team with direct experience with moving from idea, to CAD, to functioning prototypes. This includes understanding of the considerations necessary when designing in sheet metal, including fine laser cutting tolerances and the much more coarse bending tolerances.

The prototyping also provided insight into the many aspects that needs consideration to create a functioning product. In this case, this includes hydraulics, interfacing with the tool carrier, dynamic forces, material selection, screws, hoses, welds, surface treatment, and maintenance.

# Creating an outline

Because of the low tooling cost of the current production, relatively expensive and non-optimised production coupled with the inherent problematic complexities, with regard to system design, resulting from very short development and iteration cycle of the current machine, it seemed prudent to consider the scale of redesign.

In concert with Henrik Sørensen, Board Director of VPM-M, the scope and reach of the thesis was discussed. It was the opinion of Henrik Sørensen, that due to the academic and unobtrusive nature of the thesis, along with the relatively inexpensive labour of students, that a bolder course would be prudent.

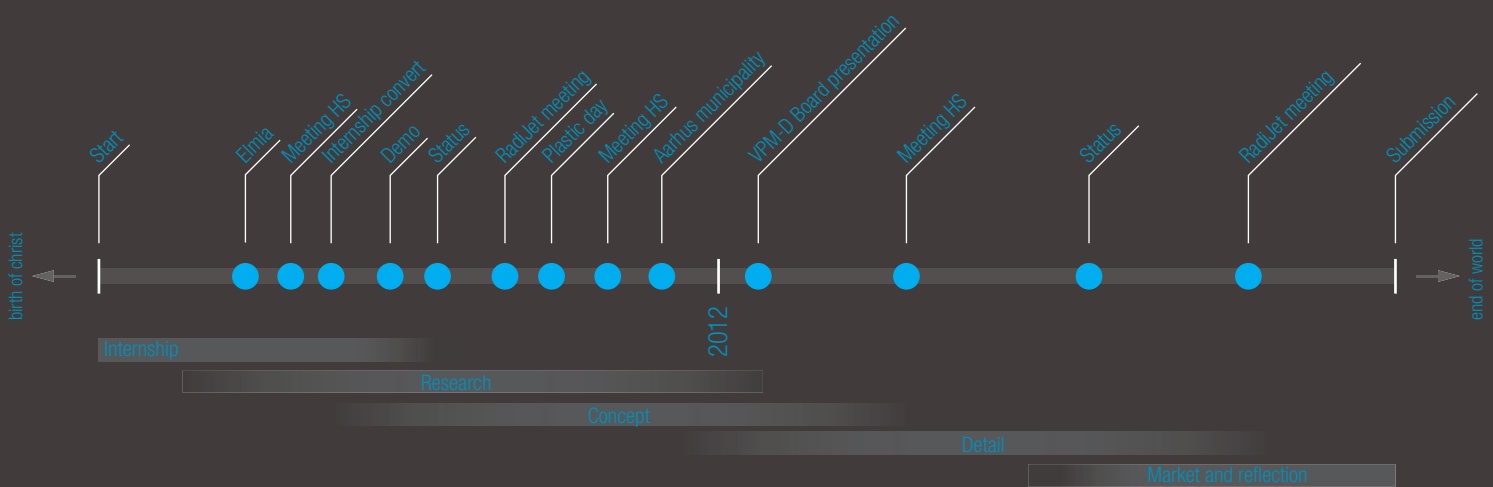
It was suggested that the project should endeavour to re-envision the tool carrier, learn from the VPM 3400, and create something radical rather than incremental. Part of the reasoning would be the advantage of having a future point of reference for incremental updates, along with a significantly higher degree of freedom in conceiving new concepts and features, that could filter down to the existing machine.

> "Best case scenario, we put the new machine into production, worst case, it would end up on a shelf, for future reference and inspiration."
> - Henrik Sørensen (HS), Chairman of the board, VPM-M

As it was made clear that the company has no future products in the pipeline, and VPM-M had not engaged in the exercise of creating a road map, the direction of the thesis would be largely up to the team. The time frame of the project would be the foreseeable future, i.e. 2-5 years.

## PROCESS OVERVIEW

As with any design process, especially those dealing in high complexity, the process is very iterative and the different phases move long side each other. Presented here is a graphical overview of the process with important deadlines and meetings.




# RESEARCH

The following research chapter will discuss the findings of the design team during various interviews, observations, and bodystorming sessions – providing a list of wishes and demands used in concept development and detailing.

The chapter will talk about the current VPM 3400 tool carrier, the immediate competitors, business analyses, user insights, branding, and future propulsion technologies.

The design team employs different methods to gather relevant data, i.e. bodystorming, observation, interviews, and business analyses.

The concept of “bodystorming”, where the designer puts him or herself physically in the users position, is widely used throughout the project to gain a broad understanding of the tool carrier and work situation and uncover latent needs. This is complemented by observations, that in this thesis revolves around the users and their interaction with the machines during a sales situation. A situated interview is conducted with workers employed in the outdoor upkeep industry, with the express purpose of understanding a typical day at work.

Various business analyses are also employed to understand the state of the market, threats, opportunities,  and strategies to move forward.

# VPM 3400

The VPM 3400 tool carrier was introduced in 2010 with the express purpose of competing against Nilfisk-Egholm's CityRanger at a slightly lower price point, offering significant improvement in one area; user comfort.

The CityRanger was disassembled and improved upon to create a machine that could compete; significant new features includes:

- Independent suspension on all wheels, where there was none before
- Well-sealed cabin, with sound deadening, resulting in significantly lower noise levels
- Larger, brighter cabin

The 3400 project was completed in 10 months, of which three weeks were used on designing the machine. The majority of the time was spent on sourcing components and creating documentation for assembly.

In creating new value and lowering the price point, VPM-M has effectively engaged in value innovation, focusing on competing on value rather than price [Kim & Mauborgne, 2012].

*"Well, the 3400 was made to take Egholm. They have become large and slow. We were told to make it by the board. MI [Maskinhander Indkøbsringen a.m.b.a.] sells a lot of Husqvarna lawn mowers, which are poor at cutting grass, but with excellent comfort. So there has to be something of it."*

*- Frank Christiansen, designer of the VPM 3400 (pictured left)*

# 3400 Jobs

## VERSATILITY

The very nature of a tool carrier entails versatility, allowing for a single machine to be tailored for specific tasks as needed. The machine can be converted to clear leaves in the fall, shovel snow and spread salt in the winter, clean thoroughly in the spring, and cut grass and hedges in the summer.

It is interesting to consider that the street sweeper attachment (a vacuum box on the rear and a sweeper on the front) is the most popular attachment. Half of VPM tool carriers are sold with a such an attachment. This is also the only tool where the front and back interconnect, and does so via a vacuum hose routed under the cabin [LBD 1, 2012].

### FRONT TOOLS

- Sweeper (street sweeper)
- Single plough
- Hedge trimmer
- V plough
- Rotary snow brush
- Grass cutter
- Gas burner

### REAR TOOLS

- Vacuum box (street sweeper)
- Salt spreader
- Salt layer
- Gas storage
- Truck bed








# Demo

To gain some insight into the VPM-M product and position and observe customers and users, it was arranged for the team to accompany the VPM-M sales representative Stig Møller on a tour of duty. This consisted of a demo at a housing association and an open house event at Havdrup Maskinforretning A/S. Following are highlights from these, see appendix A for extended version.

During the demo, where everyone was afforded a ride, it was immediately apparent that the workers appreciated the low noise levels and actively commented on it. It was also remarked that it was not easy to enter the vehicle.

During the demo, the attending clientele consisted of the entire workforce, not just the top people, suggesting, that in this case at least, the users were also the potential customers. The individuals were of all shapes and sizes, male and female, caretakers and superintendents.

The demonstration Stig Møller provided largely revolved around the comfort levels and using the machine to clean specific areas, showing how the VPM 3400 could manoeuvre and clean in tight spaces. It was important to allow every member of the workforce to have a go in the machine, to demonstrate suspension and noise isolation. Beyond that, emphasis was on demonstrating easy maintenance, cleaning and changing of equipment. Price and curb weight (because of the issue of “delicate” tiles and lawns could be damaged) was also highlighted.

The user in question thought the vehicle was slow, but was surprised to find out afterwards that she had reached the top speed of 25-30 kph. A testament to the suspension and noise isolation.

A demonstration of a relatively easy, but visually potent cleaning.

Stig Møller quickly adjusts the mirrors to deflect attention to the fact that it requires two people.

# Demo

The open house event, held at Havdrup Maskinforretning A/S, displayed many different brands, including Belos, Timan, John Deere, and VPM. The event was mainly focused on caretaker equipment, though not exclusively. The main aim was to get a foothold with clients and book future demos, not unlike the aforementioned.

This event, where different types of machinery were represented, was a chance to meet more diverse clientele. Ranging from private individuals, to an independent contractor, to workers from Boligselskabet Sjælland with 220 employees and administrating 12.500 residences. This was also an opportunity for the design team to bodystorm the VPM 3400 extensively to become intimate with articulated steering and tool change and operation. [Boligselskabet Sjælland, 2012]

One half of the design team engaged in demonstrating mounting of salt spreader on the VPM 3400.

Diverse clientele attending the open house event. The VPM 3400 was largely dismissed until potential customers were challenged to take a ride.

Limited vision of the tools during operation of street sweeper attachment.

When driving faster, the VPM 3400 has a tendency to bob back and forth due to the short wheel base and suspension.

When riding in the VPM tool carrier, the cabin felt spacious in comparison to competition. It was also clear that during operation driving both back and forth is a common occurrence, especially when changing tools or manoeuvring close to walls and corners. While changing equipment on the front is not decidedly difficult, it does require precision and knowledge about the specific attachment, as to not push it away during mounting. The process it two-fold; first is moving the tool carrier into place and elevating the arms to grab the equipment, second is getting out and locking the mounting in place and connecting the hydraulics which should be done with the engine turned off remove pressure in the hydraulic system due to safety concerns.
Because of the nature of articulated steering, with its axis in the middle of the wheelbase, the relatively far away tools moved a lot when only turning slightly, resulting in difficulty predicting where it would go when manoeuvring.

Demonstration of how low the tools are in the field of vision through the window. Arm located approximately half way up.

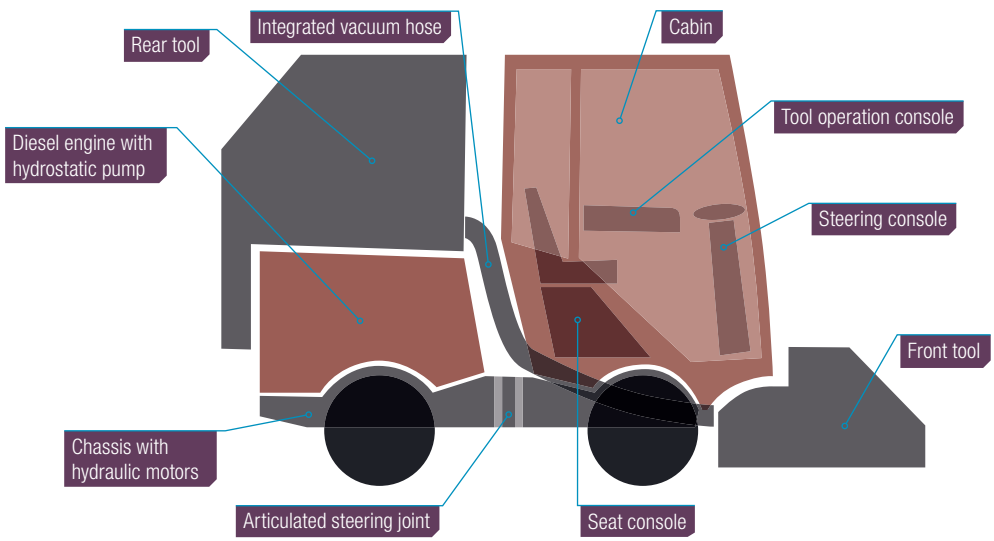
Manoeuvring the VPM 3400 in a tight spot is quite possible, however the protruding mirrors have a tendency to collide with walls, etc. causing misalignment.

# 3400 Composition

To conclude on the information gathered during the excursion, the machine and its components are described in detail from the design teams point of view. This is done with regard to main segments, engineering, aesthetics, and operation.

## MAIN SEGMENTS

Here is a simplified overview of the main segments that make the VPM 3400.




## ENGINEERING

The machine is powered by a 34 bhp turbo diesel engine, providing pressure for the hydraulic system the drivetrain is based upon. Hydraulics operate the wheels, the steering, and the tools. The VPM 3400 seems to be generally well-engineered, both structurally and mechanically. The company rarely gets any complaints of failing parts, in fact, sometimes unsolicited praise from customers. This has been achieved by making sure that the sheet metal is thick enough, the welds long enough, and a general over engineering approach. This has resulted in a tare of 960 kg without attachments, a for its size, relatively heavy machine – though not uncommon in the industry. [vpm.dk 2, 2012]

# 3400 Visuals

## AESTHETICS

In general, this machine looks like it belongs in this industry; it has a very industrial construction coupled with a vivid colour. The prevalent use of standard components is obvious and dominating. Nothing in the machine feels bespoke or special. Because of this, the construction is based around brackets and standard mounting solutions that give a sense of patchwork or indifferent modularity. Few things are aesthetically integrated, seams are misaligned and rough, and transitions in materials and textures are abrupt.


Even though there are many protruding elements, creating visual unrest, the designer has had aesthetic considerations. The slight curve of the front windscreen is a deliberate choice, as Frank Christiansen remarked: “It looked horrible without that curve.”

## SEGREGATED BODIES

Without any tools connected, machine seems unbalanced. In particular, the gap and the seemingly small joint in the middle looks fragile - even though it is very strong.

# 3400 Driving

## OPERATION

The operation of the VPM 3400 is in generally easy to grasp, though not entirely intuitive or compensating. The steering requires getting used to, but has potential precision and high manoeuvrability. The throttle controls both acceleration and braking, due to self-braking individual hydraulic motors at each wheel. The throttle response is both heavy and sensitive, requiring a delicate touch and diligence.

Mounting the equipment is not difficult, but requires patience in the beginning; precision and experience when in a hurry. The operation of the attachments is controlled solely by a panel under the right arm, where the 12 switch-buttons are laid out, and the intended function is hard to discern from looking because of the generic icons. The steering wheel is in an awkward position, and the steering console gets in the way of legs and vision.

As is evident when using the machine, a clear view of the tools and dials is not always possible.

This tool carrier size is both very agile and has a tight turning circle. The articulated steering is excellent when following a curve.

**ONCE EVERYTHING IS UP AND RUNNING, OPERATING THE VEHICLE IS RELATIVELY EASY TO USE, REQUIRING ONLY STEERING, AND OCCASIONAL TOOL ADJUSTMENT**

# Elmia trade fair

To compare the VPM 3400 to the competitors, and to get a sense of the industry in general, the design team attend a trade fair in Jönköping, Sweden called Elmia Park and Golf 2011. At this fair, both direct competitors as well as smaller and larger machines were displayed alongside VPM-M's offerings. Competitors such as Belos, Timan, Nilfisk-Egholm, and Hako.

This fair was an opportunity to observe and bodystorm the machines that constitute the industry standard. This was to give the team a holistic picture of the competitive environment, and an opportunity to explore technical solutions, product detailing solutions, emphasis on user comfort, and differentiation.
Following are highlights from the trade fair, see appendix B for extended version.

The general impression is one of a "stagnated" industry, in the sense that little user driven innovation is present. There are generally no immediately clear unified product strategies, and the machines themselves often seem unfinished or rushed. While all machines do a somewhat satisfactory job of removing leaves and snow, little importance seems to have been placed on everything else, leaving the products feeling one-sided, inelegant and industrial – both in appearance and operation. An industry where there is ample opportunity for improvement.

# Elmia trade fair



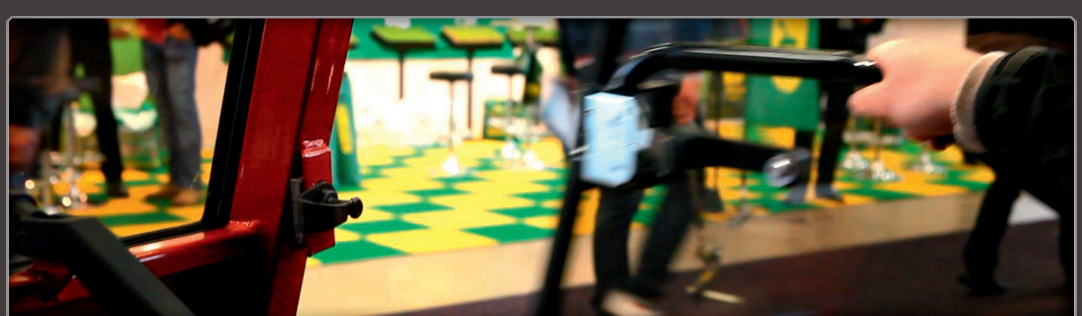
A common sight in the industry is the tendency to affix components as an after thought, often resulting in undesirable consequences.



Interestingly, in much larger machines, light fabric and panels are used in the interior, creating a much more luxurious setting. The orange plastic pictured here, has a paint-like finish, even though it was vacuum formed sheet plastic.



Even though frame-less glass looks elegant, when used in this industry it generally is impossible to close because of tolerances. These large, unresolved tolerances are found in many places.



One very overshadowing issue that is industry-wide, is the force needed to close doors - which then create a high pressure in the cabin that is quite painful on the ears. This is coupled with a cumbersome experience when entering and exiting many of the machines.

# Competitors

Even though the VPM 3400 only focused on competing with the Nilfisk-Egholm CityRanger, it makes sense to take a look at other competing companies' offerings with the experiences and information gathered at the Elmia trade fair, to examine their features and price points. Prices are stated without tools.

In general there are no extraordinary differentiating features other than size and tool capacity.

## NILFISK-EGHOLM CITYRANGER 2250

As stated the CityRanger is a direct match to the VPM 3400, an has its popularity due to a strong marketing effort and a consequent design philosophy of easy operation and consistent aesthetics. Smart coupling systems, price, and brand sell this machine.


Price: DKK 240.000

## BELOS TRANSPRO 3440

Also a direct size match, the TransPro is a product that has an strong marketing engine behind it via the owner, Kärscher Group. Belos has a more distinct and consistent design language than others and is recognisable, not only because of its yellow colour. Brand and price sells this machine.


Price: DKK 240.000

# Competitors

## HAKO CITYTRAC 4200

Slightly bigger, the CityTrac is only sold with tools, pictured here with the most popular, the street sweeper. Hako one of the older companies in the tool carrier industry, has the benefit of a name with legacy. Size and reputation justifies the price tag.


Price: DKK 500.000

## TIMAN TOOL-TRAC

A size match for the VPM 3400, the Tool-Trac is a slightly different approach, as it also has a lift arm suited to heavy truck-style lifting, justifying its price tag.

Timan is a minor player.


Price: DKK 378.000

To an industry outsider, the only major difference would seem to be the colour scheme, and that assumption is not far off. These machines are sold by salesmen during demos and in direct contact with the customer. Many times it is a case of putting on a good show, along with having a recognised brand that gets the contact in the first place. The major players in the tool carrier business that have huge brand presence make sure to capitalise on it when possible, through larger contracts with municipalities, housing associations, and maintenance companies. The way that VPM has gained entrance into the market, has been to address the small customers that the larger Nilfisk-Egholm is not that interested in.

Although easier said than done, one strategy VPM could employ to challenge the larger players, would be to create a high profile product, enabling brand promotion and eventually penetration to compete against the strong identities said players embody.

# Business analyses

The following business analyses are performed in order to enlighten the design team as to the current state of VPM-M's products, an overview of the market, and investigate future strategies.

For Boston matrix and SWOT for VPM Electro, see appendix C.

## STRENGTH

Small new company with agility and no "baggage" gave 3400 an edge in user centred design

Development-wise stagnated market, **vast improvement** possible

## WEAKNESS

Current product has **"darling" status**
**No resources to develop new products or updates of significance**

Cannot **super optimise** production

Competitors can (relatively easily) **update to compete** directly

Unwieldy competitors may choose to compete on **super optimisation**

## OPPORTUNITY

Competitors have **vast monetary resources**

## THREAT

## SWOT

As the SWOT shows, VPM-M has produced a competitive product, but in doing so, have expended almost all resources, and are now only focused on being able to keep up production, and turning into a profit. Because of the short development cycle, the machine was not optimised for production, and resulting is a product that cannot be made cheaply enough to compete if the rivals decide to lower the price point. At the same time, it might be reasonably easy for the competition to incorporate the features that set VPM-M apart.

A possible venue for VPM-M to explore in future products, is to incorporate a fundamental difference in construction and features set that would be hard to copy, to make their position more secure. This makes sense, since the company has entered the market on the premise of doing things a bit differently, with a new and unique approach of focusing on user comfort - and has thus entered the market on value rather than price.

# Business analyses

### THREATS OF NEW ENTRANTS

Entry barriers
- Few and easily observed regulations
- Common technology
- Low scale threshold
- Some brand franchise
- Access to distribution channels

Exit barriers
- Independent businesses
- Low exit costs
- Salable assets

**HIGH**

## PORTERS FIVE FORCES

The porters five analysis is conducted to understand the state of the market. Because of the low buyer and supplier power, and the development-wise slow-moving industry, coupled with entry barriers that are easily coped with, it becomes clear that the threat of new entrants is high. This is exactly what VPM-M has done, suggesting that the strategy employed is sound.

### SUPPLIER POWER

- Many competitive suppliers, standardised products
- Suppliers not concentrated
- Relatively low supplier switch cost, except custom articles with tooling

**LOW**

### RIVALRY AMONG EXISTING FIRMS

- Large number of firms
- Slow market growth
- High fixed costs
- (High storage costs)
- Medium switching cost for customers
- Low levels of product differentiation
- (Strategic stakes are high)
- (High exit barriers)
- Low diversity of rivals

**MED**

### BUYER POWER

- Many buyers with small market share (fragmented)
- Some easily accessible buyers with large market share
- Some buyers purchase a significant portion of output
- Producers can (and sometimes have) take over own distribution/retailing
- Significant buyer switch costs, depending on situation

**LOW**

### THREAT OF SUBSTITUTE PRODUCTS

- Adaptable products from related (scaled) industries
- (Automated cleaning robots)

**LOW**

## BUSINESS STRATEGY

One of VPM-M's limiting factors are the strong opposing brands, which could be challenged with added value. The current product sells because of value rather than price, a strategy that seems prudent to continue. VPM-M faces a couple of threats. They are still a small company, and could be severely undercut by the competition, long enough for bankruptcy. The added value could conceivably be incorporated into competing products, and just as VPM-M was a new entrant, another aggressive new entrant could arise and challenge the entire industry.

The design team feels the strategy for a future VPM-M product should include a strong brand-able profile, continue compete on value as opposed to price, and incorporate measures that secure uniqueness - i.e. hard to copy.

# Delimitation

To focus efforts, a set of limiting boundaries is listed. These are:

- The project will focus on re-envisioning the tool carrier concept where an operator is required.
- The most popular tool, the street sweeper, will be included.
- The VPM 3400 will function as a size reference. It is the opinion of the design team that this size machine strikes a balance between agility, capacity, and operator space.
- The Danish market will serve as reference environment.
- The scope will be limited to the current tool carrier market.
- The project will focus on the professional market rather than consumer.
- The project will observe regulations with regards to cabin stability (safety) and light placement.
- Investigate the user experience to compete on value rather than price.

# A PLACE OF WORK

In order to get an insight into what a typical day for a tool carrier operator is like and uncover needs and wants, a situated interview with three such operators was set up. The three in question are employed by Aarhus Municipality. Following are highlights from the interview. For a complete transcript in Danish and list of initiating questions, see appendix D.

*Op 1 – "Well I think that the noise could be even lower, you know, it is something that you constantly sit in."*

*Op 2 – "But you could do the same kind of suspension like in a car, that would make for a smoother ride, that's for sure."*

*Int – "How is it annoying [to get in] in the winter?"*
*Op 2 – "Because there you dismount the lawn mower, and that is what you use as a stepping board to get up"*

*Interviewer – "What kind of stuff do you bring with when you are out? Do you bring lunch or a cup of coffee? Or a folder with something?"*
*Operator 1 – "Well, we bring the lot. We've got lunch, water and coffee."*
*Interviewer – "So you take lunch in the machine?"*
*Operator 1 – "Yes."*

*Int – "I was thinking more of if you saw a really cool machine, if you would want drive around in that?"*
*Op 2 – "Of course!"*
*Op 1 – "Well, I only look at interior and noise level."*
*Op 2 – "Yes, that's the most important thing…"*

*During tour of the machine:*
*"Yes, we put our own seat in. We also put in a fridge for our lunch..."*

*Int – "So you are out [of the cabin] a couple of times a day?"*
*Op 1 – "Very much so…"*

The interview was partly constructed on the bodystorming findings of the design team, as to correlate these experiences with the statements of the operators. In many cases the workers verified the issues identified by the design team with regards to user interaction. This includes the boarding action, fields of view, noise levels, and the cabin as a place of work adapted to the needs of the operators.

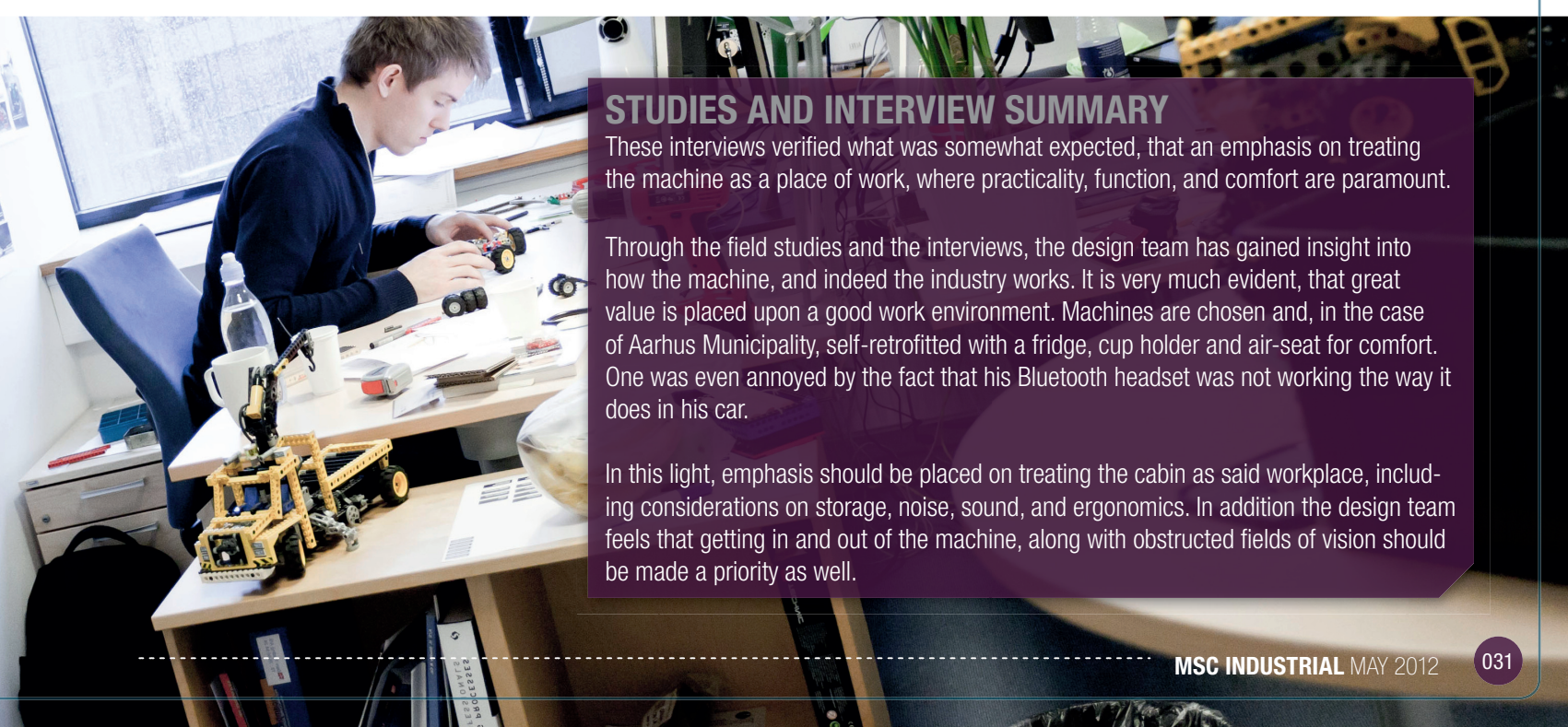
## INTERVIEWS - VIA VPM DEVELOPMENT

The design team has been afforded access to focus group interviews conducted by VMP-D in order evaluate the VPM 3400 and gauge impressions of a possible electric edition. The interviews are conducted by Martin Lund, Market Researcher at VPM-D.

Three interviews were conducted in Aarhus, Copenhagen, and Ringkøping-Skjern municipalities. Workers were given a VPM 3400 for an evaluation period, and interviewed afterwards. For complete interviews, see appendix E.

Summarised, the workers generally liked the machine, albeit their needs revolved around slightly larger machinery of similar type. While that could have made the evaluation somewhat skewed, the design team still believes there is merit in the comments. In summary the most prevalent comments on the machine were:

- Getting in is not easy with doors hinged at the front, and preferable both sides should be accessible.
- Protruding head lamps get in the way and could be damaged or torn off.
- Protruding mirrors are an issue, should consider rear view mirror inside cabin instead.
- The curb weight is too high when driving on soft surfaces.
- No compartments in the cabin for stuff. Folders, coats, gloves, small tools, etc. is common gear.
- Larger tool capacity is very desirable.



## STUDIES AND INTERVIEW SUMMARY

These interviews verified what was somewhat expected, that an emphasis on treating the machine as a place of work, where practicality, function, and comfort are paramount.

Through the field studies and the interviews, the design team has gained insight into how the machine, and indeed the industry works. It is very much evident, that great value is placed upon a good work environment. Machines are chosen and, in the case of Aarhus Municipality, self-retrofitted with a fridge, cup holder and air-seat for comfort. One was even annoyed by the fact that his Bluetooth headset was not working the way it does in his car.

In this light, emphasis should be placed on treating the cabin as said workplace, including considerations on storage, noise, sound, and ergonomics. In addition the design team feels that getting in and out of the machine, along with obstructed fields of vision should be made a priority as well.

# VALUE IN STYLING

## THE VPM BRAND

As suggested earlier, the main competitors have heavy brands promoted by a large marketing engine, a long history in the industry. And although the products they sell are expensive and not of particular refinement, they are quite successful in their respective market niches.

According to VPM-M CEO Henrik Christiansen, one of the early difficulties when trying to sell the VPM 3400 tool carrier, was the lack of brand recognition, i.e. none of the potential customers had heard of it and were initially dismissive.

As of this writing, VPM-M has gained some recognition for the levels of comfort and quality in comparison to the competitors, and this has helped them gain an entrance. They are held back due to lacking after sales support, inability to deliver enough machines, and a beginning sense of stagnation among customers, as VPM-M has not introduced anything new since the first machine was delivered. Currently all energy is focused on ramping up production in China, to increase volume and reduce costs. Secondary is after sales support, and no effort is currently put in updates.

It is the desire of the design team to create a product that can, among other things, enforce and define the VPM brand as an industry innovator, and continue to refocus on value rather than price.

As this project is focused on creating a radically new product, rather than an incremental one, there is an opportunity to imbue other characteristics, and thus value, than those present in the VPM 3400. One venue that seems largely untapped in the tool carrier business, is the emotional venue. According to Jens Martin Skibsted, the emotional value of a product is a key factor in creating an iconic product [Aagaard & Skibsted, 2008].

When comparing the VPM 3400 to a recent car, e.g. the Volvo S60 (the Volvo being 55.000 DKK cheaper), it is apparent that a car provokes a much more profound emotional response and has a desirability not found in the tool carrier, even though the two products are not directly comparable [SKAT, 2012] [Volvo, 2012].

*"[…] a strong, even iconic brand has always arisen from a strong iconic product. Never the other way around."*
*- Tony Aconis, Instant Icon [p157]*

# Importance of identity

A prominent character, when discussing emotional value in design, is Donald Norman, arguing that this is a powerful tool when appealing to customers. When talking about emotional design, Norman points out three key concepts; the visceral, the behavioural, and the reflective element.

"**Visceral** design refers primarily to that initial impact, to its appearance. **Behavioural** design is about look and feel -- the total experience of using a product. And **reflection** is about ones thoughts afterwards, how it makes one feel, the image it portrays, the message it tells others about the owner's taste."

- [Norman, 2004]

*"Products differ in their appeal on the three design dimensions, but so too do people and situations. Vegetable peelers are primarily bought for their behavioural aspects. Wall clocks might be bought for their visceral appeal, or their reflective image. Some people are behavioural, emphasizing the behavioural level in their choices. Some are visceral, going by appearances. Some are reflective, considering what others will think -- although it is the rare person who will admit to this trait."*

*- [Norman, 2004]*

It is the goal of the design team to utilise these notions set forth by Norman in crafting an emotionally engaging design, to create a product with a distinct identity and presence.

Bang & Olufsen Beolit 12

Like most B&O products, the Beolit 12 has a high level of "reflective" and "behavioural" quality.

Rosti garlic press

Has superb "behavioural" properties, not the most "reflective" product.

Lamborghini Reventon

The Lamborghini, and indeed many sports cars, embody all three elements of emotional design in abundance.

Knipex wire de-insulator

Has very satisfying action, comfortable to hold and use. Not the best "visceral" qualities.

# Mobility tomorrow

As this thesis is in the business of mobile solutions it seems reasonable to investigate what tendencies and forces acting as drivers of new technology and look into an industry that works up front with new technologies.

Politicians in Denmark has a clear agenda, they want to reduce emission of CO2. Thus a political pressure is on improving efficiency of motorised vehicles. Copenhagen's agenda is to be a carbon-dioxide neutral city in 2025 [CPHX, 2009].

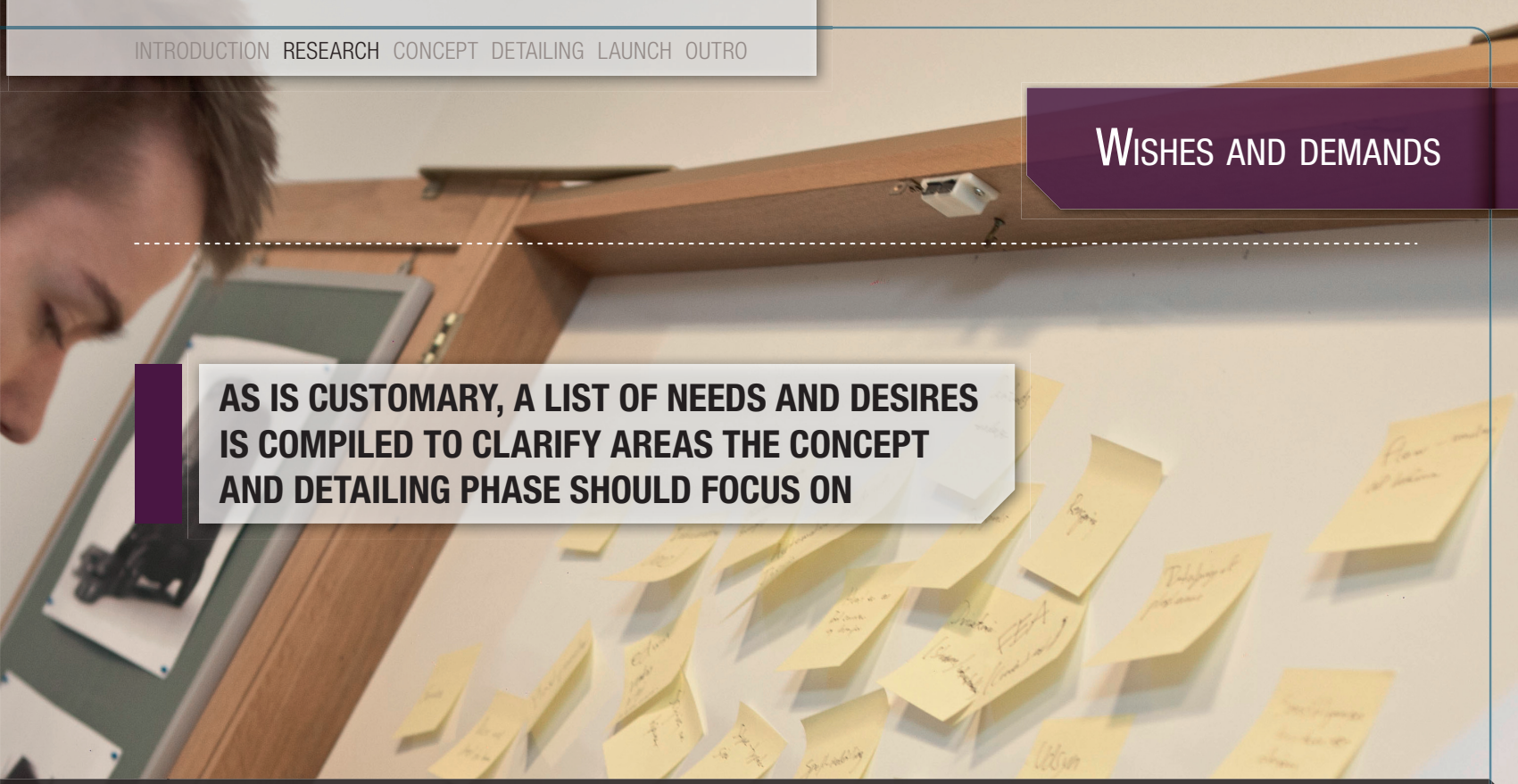
Initiatives are already numerous and primarily concern the transportation sector, where most apply electrical solutions. An electrical solution is advantageous as efficiency is higher than in conventional combustion engines, and there are many sources that provide electricity.

Relevant to this thesis, initiatives are in the pipeline e.g. EUDP project, which shows the attention paid to green cities keeping. In the city of Copenhagen, the municipality is therefore facing a transitional phase of replacing thousands of pieces of equipment powered by conventional gasoline or diesel combustion engines. One way to go which seems highly prioritised is hydrogen technology, which will be kept in mind but not pinned down as the primary solution [EUDP, 2012] [KK 1, 2009] [KK 2, 2011].

Automotive companies stumble upon each other to show how they embrace new energy efficient drivetrains and create high profile products to hit the market yesterday. Even in the extremes, Le Mans cars are taking on hybrid technology, and commercial cars that are electric one way or another starts cropping up [topspeed.com, 2012].

At this point it becomes clear that looking into automotive behaviour could be beneficial as a new guiding star for reference instead of competing tool carriers.

# Wishes and demands



**AS IS CUSTOMARY, A LIST OF NEEDS AND DESIRES IS COMPILED TO CLARIFY AREAS THE CONCEPT AND DETAILING PHASE SHOULD FOCUS ON**

## DEMANDS

### VPM 3400 LEGACY

- Low noise (not verifiable in the course of this thesis)
- Keep existing turning circle (620 mm)
- Suspension on all wheels
- Keep existing dimensions (2420 x 1100 x 1980 mm)
- Keep front tool interface
- Keep integrated vacuum (street sweeper) routing

### IMPROVEMENTS

- Wider wheel base for stability (>1200 mm)
- Field of view that allows direct visual contact with tool interface (when mounting tools), contact between tool and pavement for tracking, and a reliable rear view system.
- Incorporation of emotional design elements, in order to add value and branding potential.
- Improved facilities for entering and exiting the cabin.
- Improved door closing mechanism
- Improve ergonomics in cabin, specifically with regard to operation and readouts.
- Storage compartments in cabin.
- Reduce carbon dioxide emissions, while being able to run for an entire day (6-10 hours)
- Observe OECD cabin safety “crush test”
- Observe light placement regulations
- Remove protruding elements such as side view mirrors and head lamps

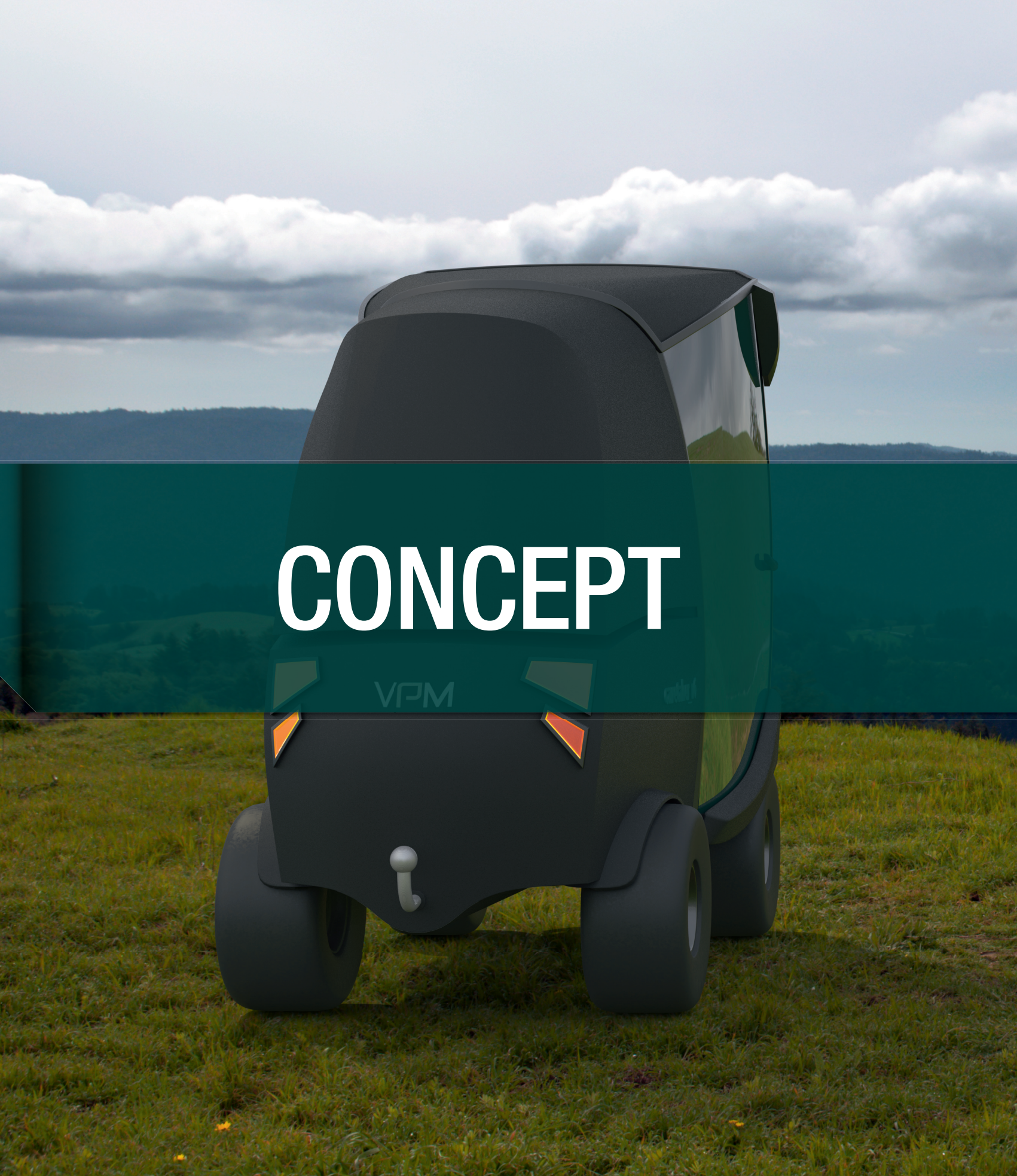
## WISHES

### TOOL CARRIER

- No noise
- Emission free
- Lower weight
- Lower centre of gravity
- Four wheel drive
- Move tools closer to wheels (to reduce swing radius of protruding tools during turning)
- Improved placement of lift arms, to avoid scraping on e.g. kerbs
- Cabin accessible from both sides
- Configuration options (e.g. with or without closed cabin, for Chinese market)
- Designed for high volume manufacturing

### STREET SWEEPER ATTACHMENT

- Increased vacuum box capacity
- Increased vacuum at mouth piece
- Ability to consume large objects, e.g. wine bottles


CONCEPT

The concept chapter explores new tool carrier concepts with point of departure in the wishes and demands outlined in the previous chapter. In developing concepts, the design team utilises experimentation with physical models, in 3D CAD, and system overviews, to arrive at a set of concepts that defines the new Flux tool carrier.

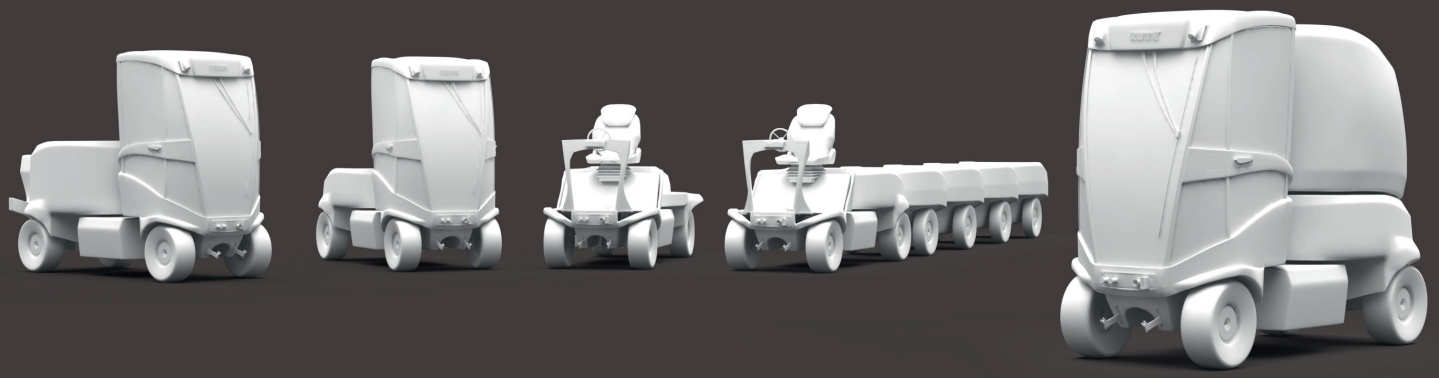
# System level design

Designing and conceptualising on a product with the complexity level of a tool carrier, requires considering the product both as an integrated whole, and as sub-components that interrelate.

Ulrich and Eppinger introduce the term system level design which is just such a method in managing the interrelation between components. It can be referred to as a product architecture, which defines different chunks within the product and how these connect to each other [Ulrich & Eppinger, 2007].

This process requires moving between components and constantly iterate as changes in one component challenges another. For the sake of brevity and clarity, these “chunks” are discussed separately. These are: Modular approach and overview, steering typologies, powertrain system, entering and interfacing, fields of view, and aesthetics.

# Modular platform



While the concept of a modular tool carrier, as currently produced by several companies, has a vital function in modern city keeping, the way the tool carrier of today is modular is with the tools attached, and configuration on the machine itself is limited. In order to accommodate other market tiers, modularity beyond attachments are explored. Pictured below is a system architecture overview.


This exercise results in the concept of a self-contained platform that gives enormous freedom in configuration – interchangeable cabins and tail ends, along with the perspective of increased capacity on the back. A platform approach also has the inherent capacity for aesthetic and functional updates, being a finite, underlying system.

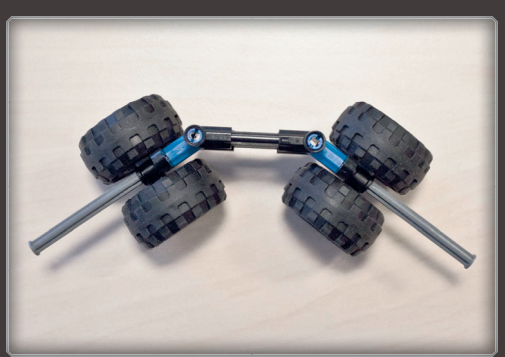
# Steering attributes

Steering is one of the most important capabilities of a tool carrier, as it is the means by which the tools are controlled.

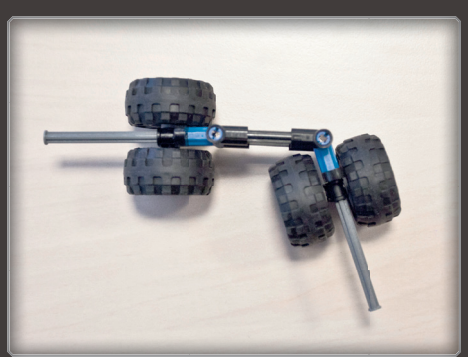
Because of a desire to challenge this fundamental aspect of the machine, mapping possible steering typologies was carried out to give an overview to which possibilities or limitation each brings – the most promising of which was double articulated steering (DAS). For typology overview, see appendix F.

## SINGLE VERSUS DOUBLE

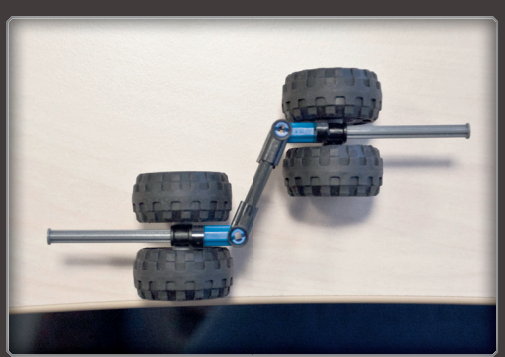
A part of the investigation was to benchmark DAS in term of performance compared to the currently used single articulated steering (SAS). The primary driver in this case is the turning radius, which should be equal or better. During this session it was discovered that with DAS, the characteristics of steering can be adjusted, bringing benefits from both SAS and four wheel steering. This e.g. means that DAS can simulate SAS, but also make manoeuvres like either a front wheel or rear wheel steered vehicle. Furthermore, it was discovered that DAS has the capacity for crab style manoeuvring – useful when moving close to an edge or on soft surfaces where a diffused tyre pressure is desirable.



DAS simulating SAS by angling both joints equally.

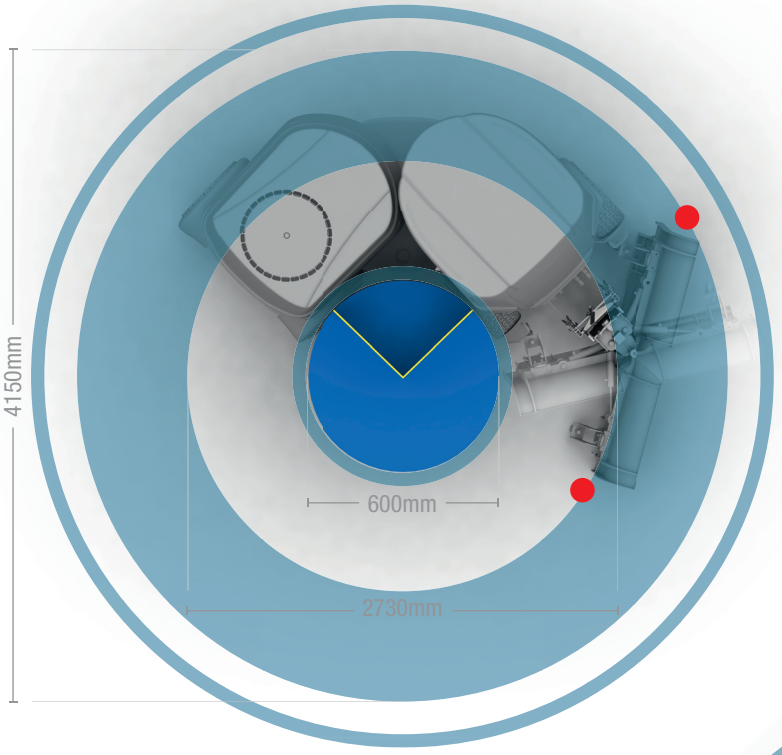


Utilising a single joint to create either rear or front wheel steering.



Utilising both joints to create crab style steering, shifting centre of gravity of machine away from ledge and widening the track.

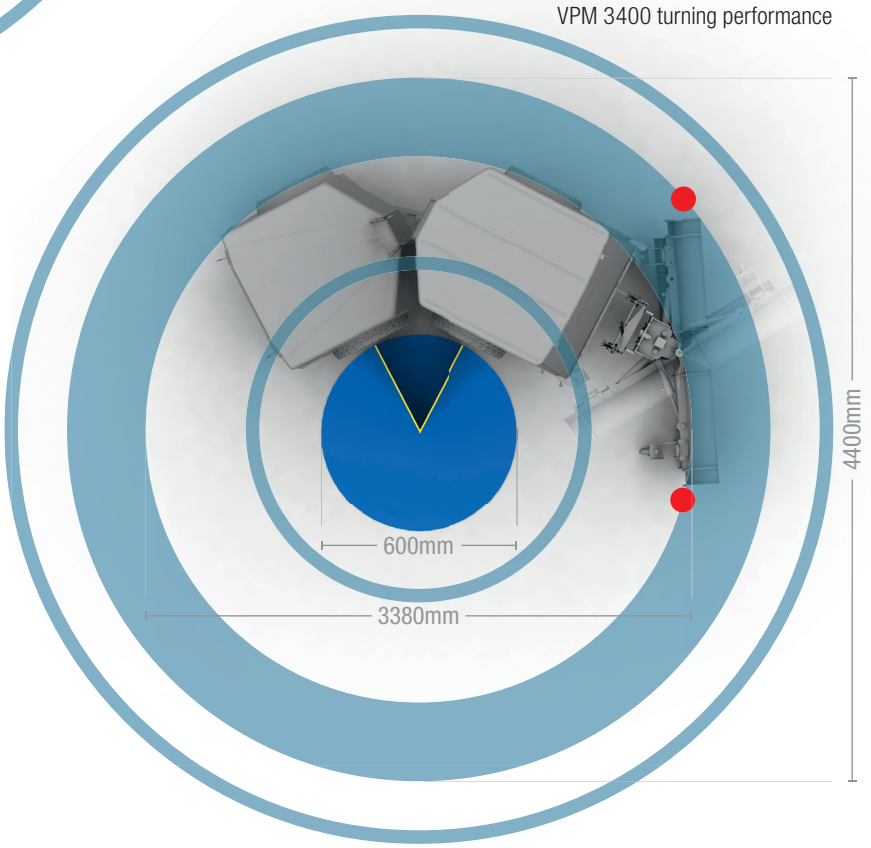
# Steering attributes




VPM Flux turning performance

DAS allows for the machine to turn around an object much tighter than SAS. In this case a snow plough is mounted to show that the extremities of the tool path are more compact, closer to street furniture. This implies that cornering performance in narrows alleys improves and lets the machine manoeuvre through tighter spaces than the current 3400.

VPM 3400 turning performance



## Steering attributes

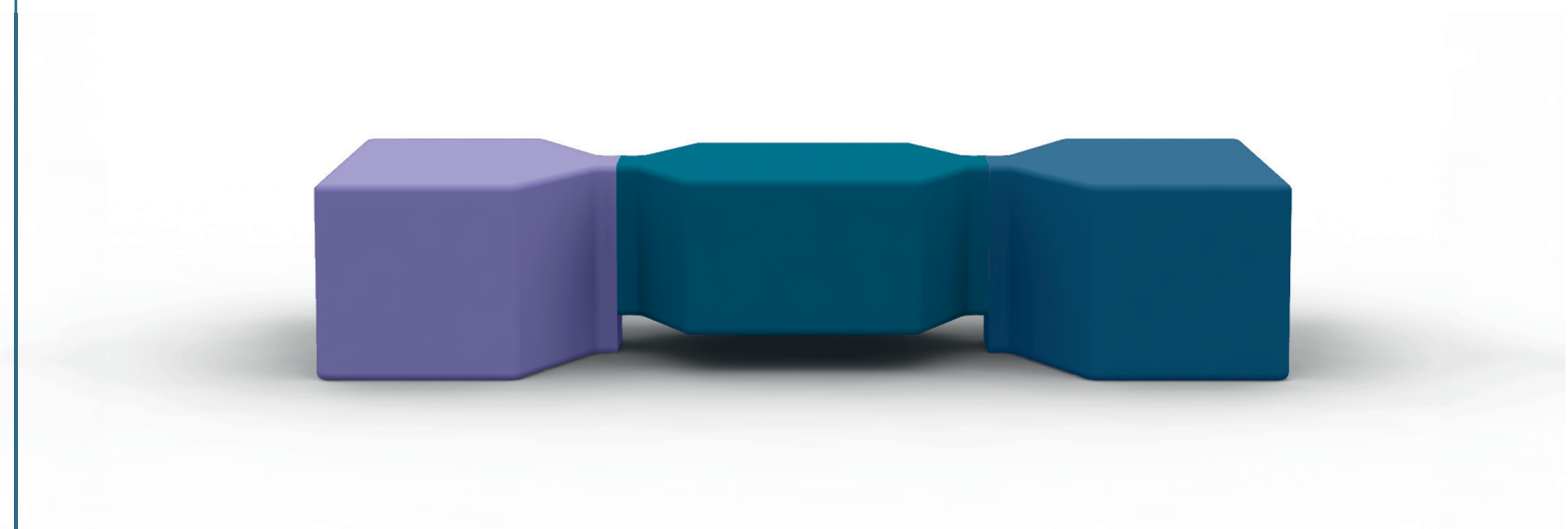
Because of the advantages in manoeuvrability, the simple nature of the joint, the wider wheel base and centre volume, the DAS is chosen as the steering typology. This also integrates with a self-contained platform, as there is a large, coherent, and unoccupied volume to utilise in the centre.

### CHALLENGES
- Added complexity and cost
- Requires electronics to keep alignment

### BENEFITS
- Simple, compact, and proven joint system as it is closely related to SAS
- Slightly better turning circle than SAS
- Improved tool paths
- Ability to simulate SAS
- Allows front, rear and crab steering
- Creates wider wheelbase
- Creates vacant centre volume

# DAS

**DOUBLE ARTICULATED STEERING, ENABLING LOW SLUNG DRIVETRAIN THROUGH A NEW, UNOCCUPIED CENTRE VOLUME.**



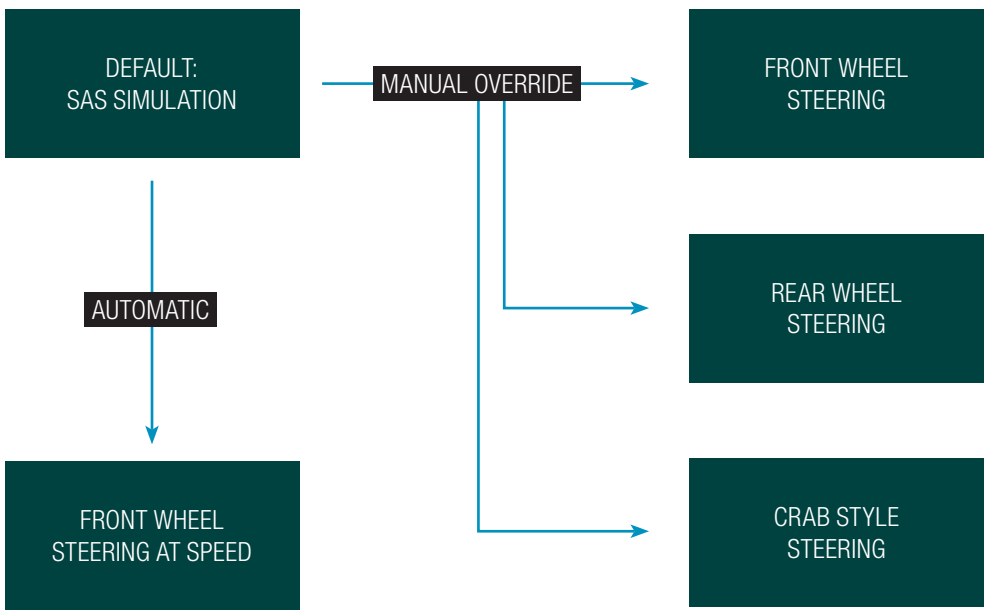
# STEERING ATTRIBUTES

## TAMING THE STEERING

One obvious obstacle when having four available types of steering in one system, is when and how said systems should be utilised. To encourage simplicity, the design team suggests creating an electronic system that automatically selects mode according to circumstances and takes care of aligning the two joints. One of the dangers of this approach, however is creating unforeseen conflicts between operator expectation and programmed automation.

*"I believe there are solutions. Firstly, if you can automate something reliably all the time, do so. It helps make our lives easier. […] We automate more and more in the home, we don't have to worry about regulating the temperature. When we can't automate all the way, then how about making it voluntary. How about making it so that if you know what is going on, then you can handle it, or, it offers suggestions. […] As long as the two systems [man and machine] don't fight each other, we're okay."*

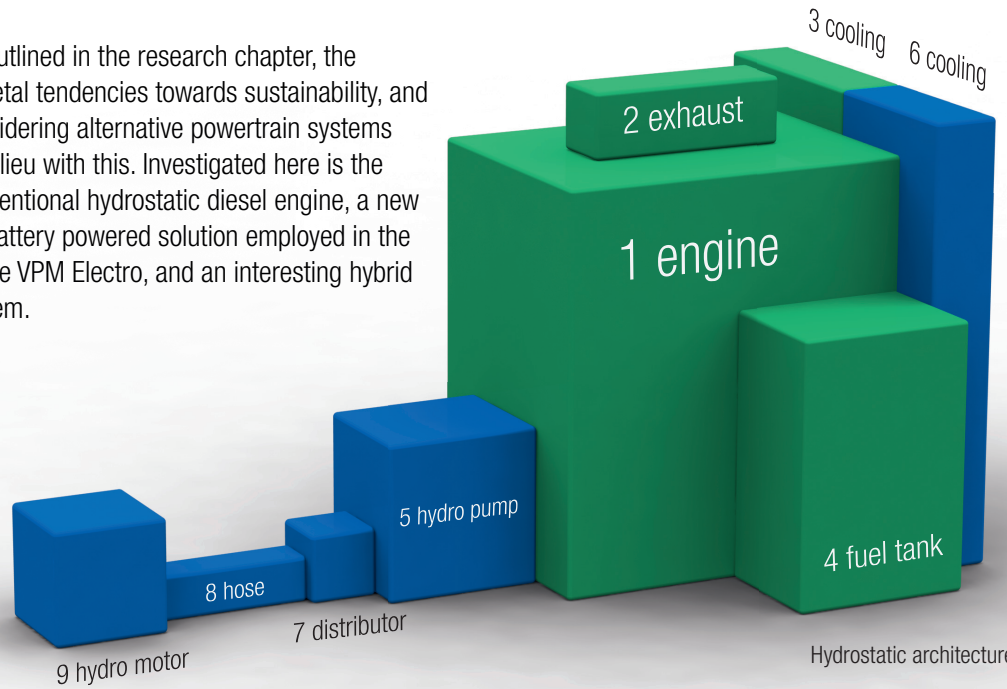
*- [Norman, 2007]*




In this light, it seems wise to implement a cruise feature, automatically steering on front wheels above a certain speed, however, creating a steering macro to be automatically invoked when careful and deliberate steering is called upon may not be. It is the opinion of the design team, that while more efficient steering could be attained though automation, it might be counter-productive, unintuitive, and perhaps contain an element of danger (such as e.g. property damage). Thus default mode is suggested as simulated SAS, with the option of manually selecting front, rear, and crab style steering – along with gradual automatic selection of front wheel steering when travelling at high speed.

# Powertrain variations

As outlined in the research chapter, the societal tendencies towards sustainability, and considering alternative powertrain systems is in lieu with this. Investigated here is the conventional hydrostatic diesel engine, a new all-battery powered solution employed in the future VPM Electro, and an interesting hybrid system.




Hydrostatic architecture

## CHALLENGES
- Overall efficacy is low
- Inflexible power source positioning
- Maintenance
- Overheating
- Noise and emission control

## BENEFITS
- Easily implemented four wheel drive (hydro)
- Refuelling

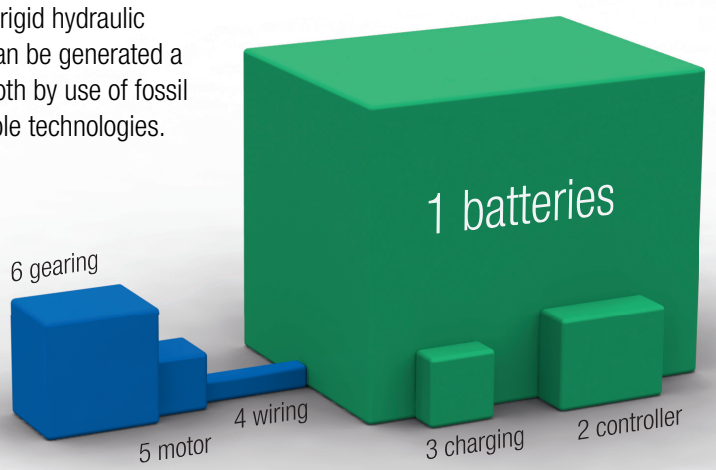
No gearing necessary (hydro)

## ELECTRIC BENEFITS

In an all-electric solution the fuel tank and engine is replaced by batteries. The batteries then powers geared motors through a wiring loom. One interesting aspect is the compact and flexible nature of wiring loom, that replaces the many rigid hydraulic hoses. Electricity can be generated a number of ways, both by use of fossil fuels and sustainable technologies.

## CONVENTIONAL COMBUSTION

A well-known and tested technology, energy is usually provided via a diesel engine with either a hydrostatic system or a gear drive solution. Most current tool carriers employ hydrostatic solutions.

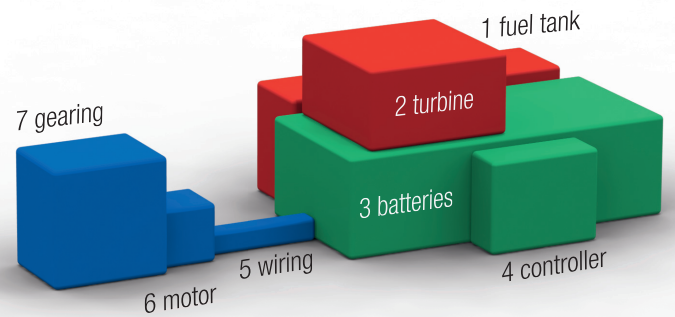



Electric architecture

## CHALLENGES
- Charging and run time
- Young technology
- Weight
- Initial price

## BENEFITS
- High efficacy
- Low noise
- Flexibility
- Upgradeability
- Low maintenance

# Powertrain variations




Hybrid architecture

## CHALLENGES

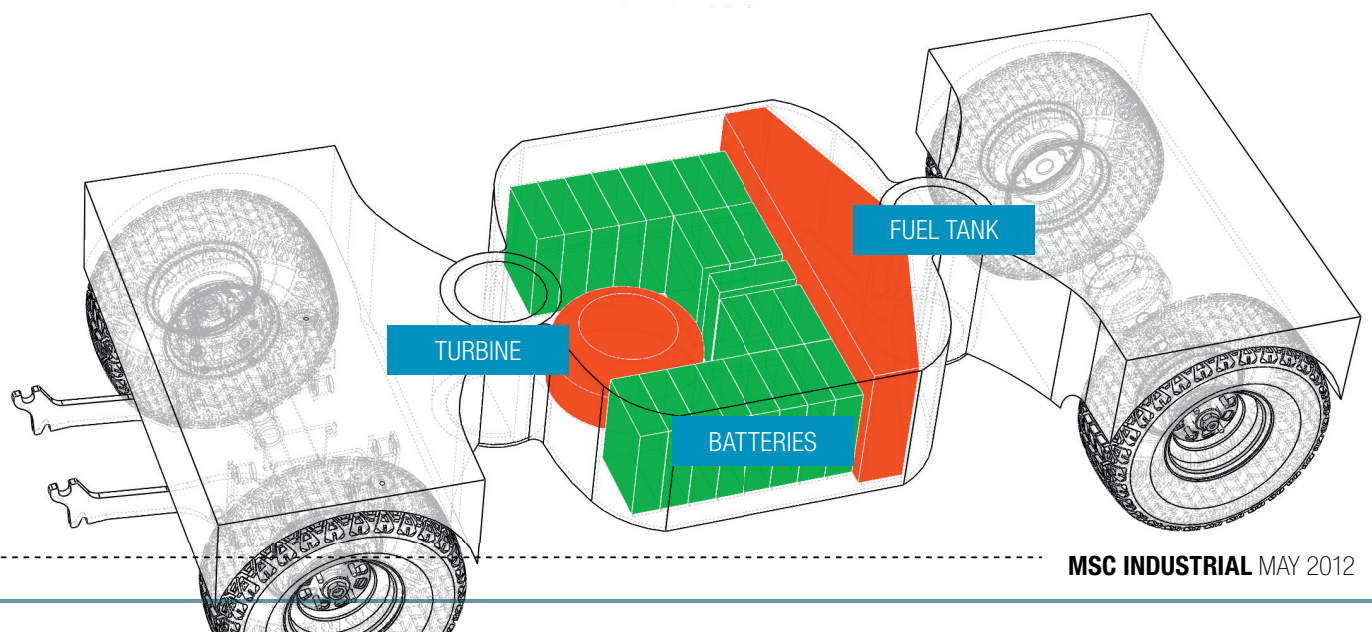
- Integrated battery management system
- Time to market

## BENEFITS

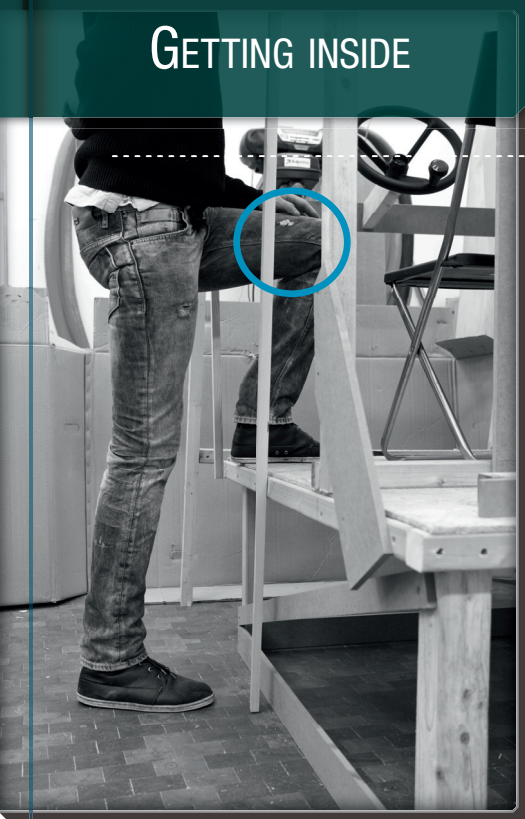
- Compact and low profile
- Light weight
- Immediate high performance [Christensen, 1997]
- Easy and fast refuelling
- Supports many types of fuel (gas and liquid
- Same as AED

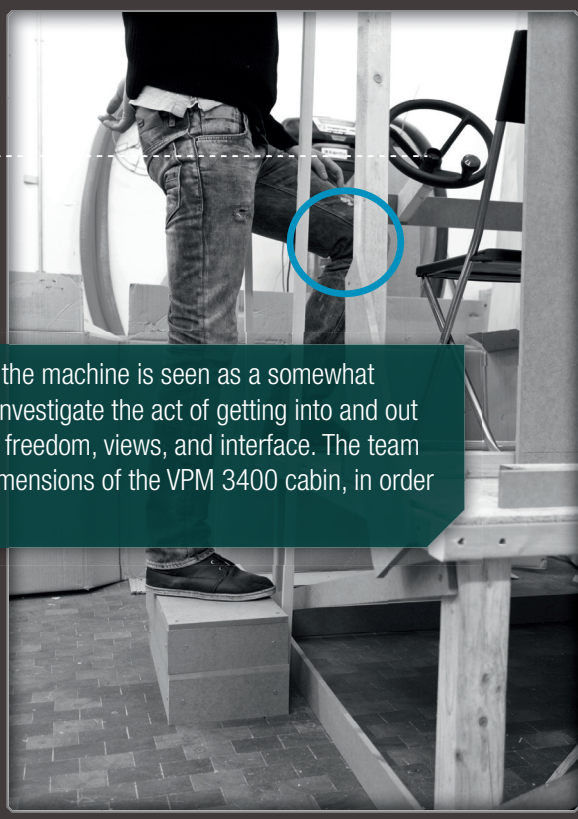
## BEST OF BOTH WORLDS

Creating a combination of conventional combustion with the benefits of an electric infrastructure has its merit in this industry. This is because an all-electric solution introduces new performance trajectories, while under-performing on mainstream market demands. History reveals this is often unsuccessful in direct competition with conventional technology [Christensen, 1997]. A hybrid solution embraces benefits from both camps and introduces new performance trajectories, which can compete with both concepts. Combining a high performance jet turbine with an electric infrastructure introduces the best of both worlds while removing the biggest disadvantages; capacity, weight, noise, and inefficient powertrain. This hybrid solution is selected.



# Getting inside

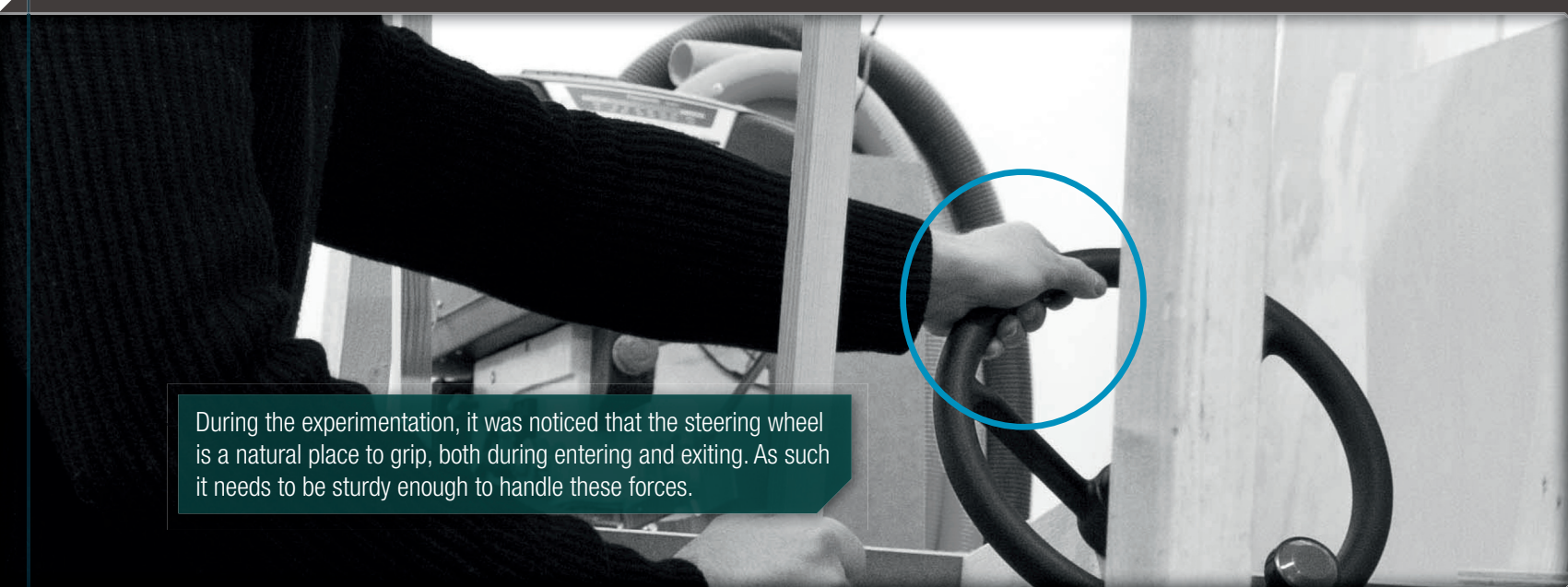




As indicated in the research chapter, boarding the machine is seen as a somewhat latent issue. This compels the design team to investigate the act of getting into and out of the cabin, as well as issues such as seating freedom, views, and interface. The team constructed a wood mock-up in roughly the dimensions of the VPM 3400 cabin, in order to bodystorm these areas.

The floor here is elevated roughly 500 mm above ground level. Even a relatively tall individual (187 cm pictured here) has a knee bent with an acute angle when no step in between is present. This puts a large amount of strain on the joint, and encourages a leaping action requiring the user to brace against the door frame.

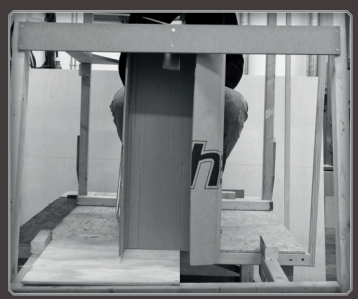
If a step is introduced at half way, the entering sequence becomes a much more relaxed walk, requiring less bracing.



During the experimentation, it was noticed that the steering wheel is a natural place to grip, both during entering and exiting. As such it needs to be sturdy enough to handle these forces.

# A FLAT FLOOR

An early obstacle the design team noticed, was the tilting steering console, that significantly limits the freedom in entering, exiting, and simply sitting in the cabin.



The steering console in its current configuration requires the user to tilt it in when seated, and tilt away before exiting. It is immediately clear that this console (depicted in both tilted and upright position on the right) places notable restrictions on feet and legs.

When removing the console, a much higher degree of freedom in seating is obtained. It also prompts the discussion on how, if not on a central column, would the steering wheel be mounted.

# Angled steering

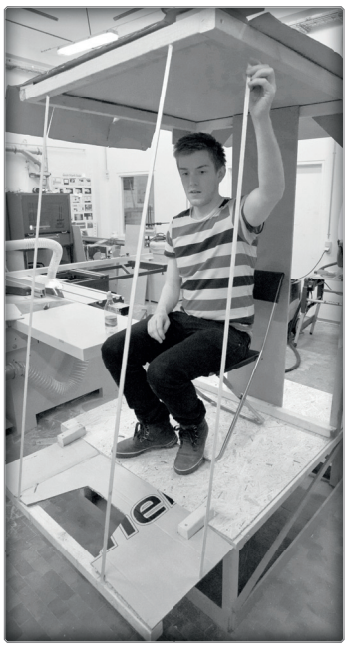
**WHEN THE MOUNTING OF THE STEERING WHEEL IS NOT DICTATED BY THE COLUMN, THE DESIGN TEAM FINDS THAT POSITIONING IT IN THE SAME FASHION AS DONE IN AUTOMOBILES IS ADVANTAGEOUS**

When angled like this, the movement of the shoulder becomes much less pronounced, and less demanding. This is of importance when manoeuvring all day long.

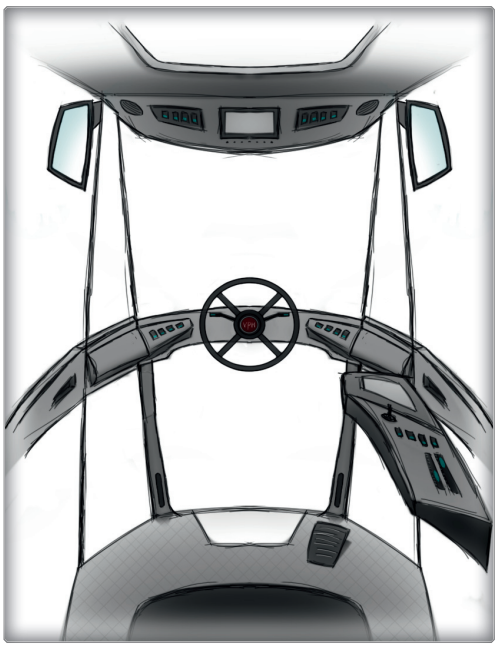
While it may be desirable to employ an adjustable angle to accomodate different users, the design team prefers the configuration depicted in the middle.

# Fields of view

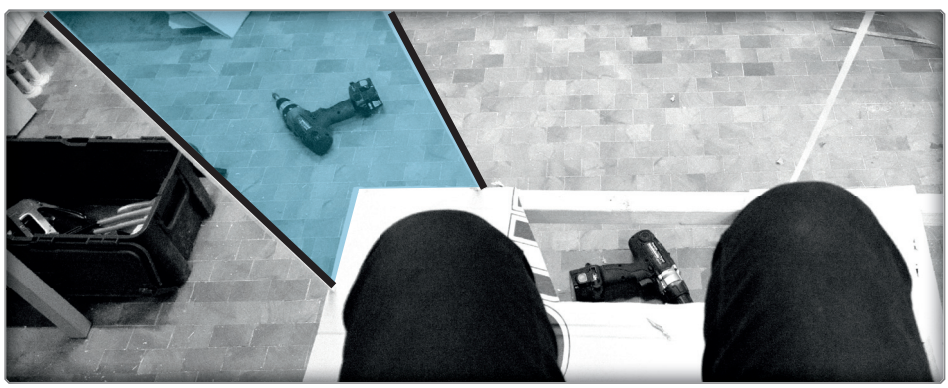
Another area the design team wished to illuminate, is the issue of fields of view. While all tool carriers employ large glass pains to offer good visibility, often the arrangement (and retrofitting) of components along with the pillars work against this.



The idea of splitting the A-pillars into two pillars, gives a clearer view of tools interfacing with an edge or kerb.

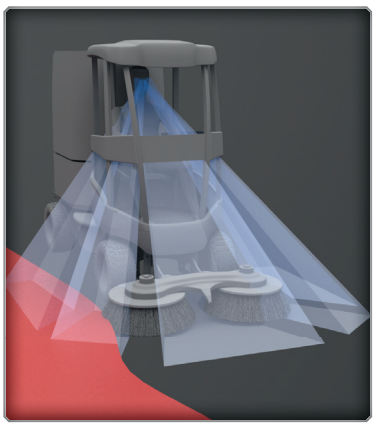


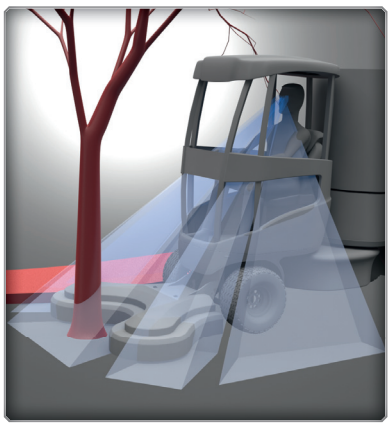
Removing the steering column and splitting the A-pillars, results in integrated band concept. The band encompasses the operator like a cockpit with all necessary controls, while providing an uncluttered floor and lower windows.



Split A-pillar showing unobstructed view of a simulated street sweeper brush.

# Fields of view



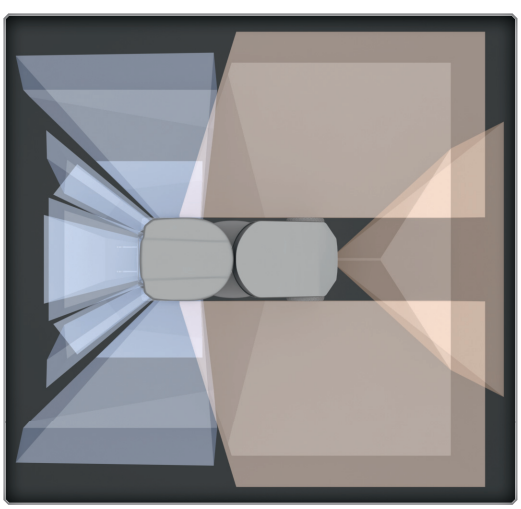


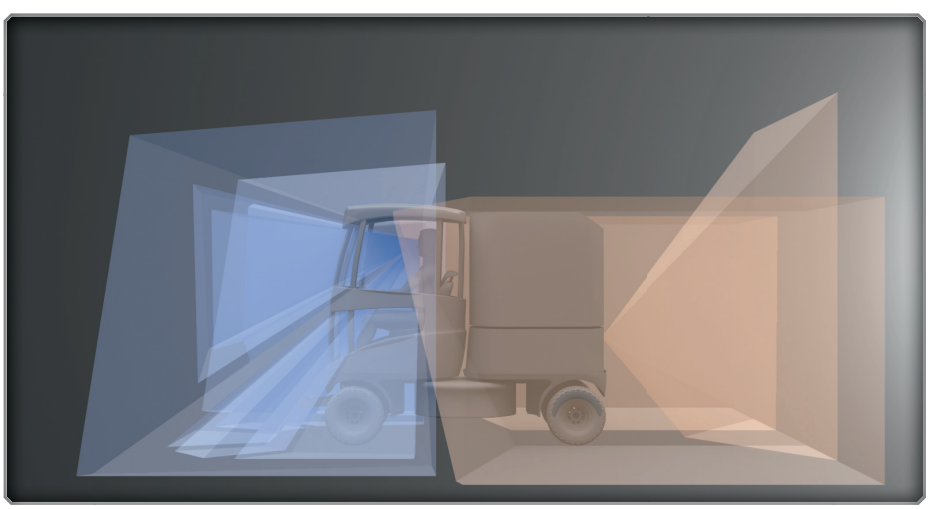
Implementing the band on a CAD model, shows the lower window band enabling excellent overview of tool operation and alignment.

Lower centre window providing direct line of sight for when attaching tool, where the steering console would be.

When considering the fields of view, the side view mirrors should also be addressed. The VPM 3400, and indeed many tool carriers, require two people to adjust these, and have a limited field of view while being prone to dislocation when driving close to walls or vegetation. The design team proposes to use fixed cameras with negligible protrusion coupled with internal screens mimicking traditional side view mirrors, but with the benefit of not being incident angle sensitive, or non-functional at any point due to dislocation. Installing a back-up camera to complement the two on the side, creates a dependable 360 degrees field of view around the vehicle. It should be noted that such a solution is not currently legal [DTA 1, 2012].

In these illustrations, blue volumes represent direct line of sight, and orange represents electronic cameras.

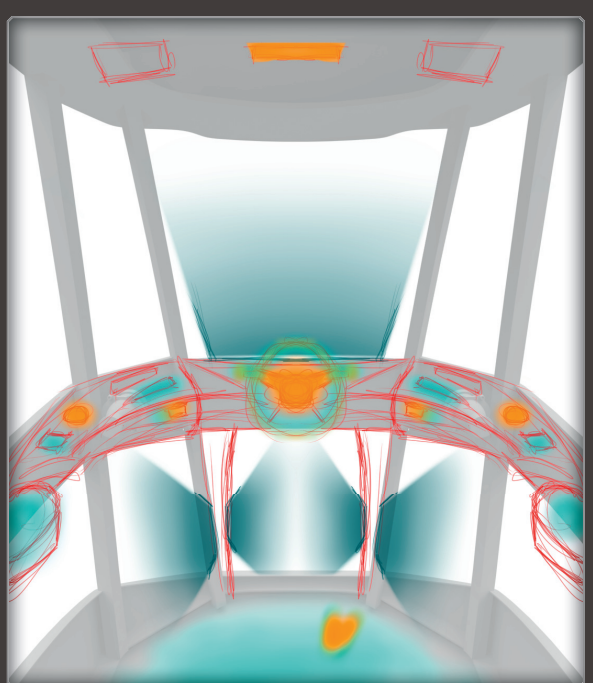




# Interior interface

Steering wheel with a central integrated screen, that provides all machine feedback in one central and unobtrusive place.

The band-cockpit concept is taken a step further, incorporating controls directly into the doors instead of a separate console. This saves on space and allows both doors to be opened completely, providing full access to the cabin from both sides of the vehicle.



This illustration is produced in an effort to create an overview of interactions and place them in a fashion that caters to the cockpit philosophy

Teal fans represent possible airflow to the windows.

Orange areas represent functional areas, where the user has regular interaction. This includes steering wheel (with central screen), indicator stalks, door release, tool controls, stereo, and pedals.

Blue areas represent support areas where arms, hands, feet rest/grab. This includes the floor, elbow and hand rest, door pull, and steering wheel.

# The visceral aspect

## AESTHETICS

The final area of the concept chapter deals with the identity-creating visceral phase. Aesthetics are often neglected or unchallenged in the industry of tool carriers, and if the distinctive colour is removed, it can be difficult for a layman to tell them apart. In lieu of the desire to create a product with striking visceral properties, to add to an emotional design, the team embarks on the challenge of creating a design language that incorporates and expands upon the VPM values set. That is emphasis on user comfort, sturdiness, and a desire to do things differently.

Early in the project, two visual directions were developed as a means to introduce the design team to the complexities of, almost, automotive design and translating two dimensions to three.




# A SPECIFIC GOAL

After these initial exercises, once powertrain and steering mechanism was sorted, a more focused effort took place. One initiative was the creation of “design direction” through values the team wishes to imbue the product with, along with examples of these.

Kind


Rugged

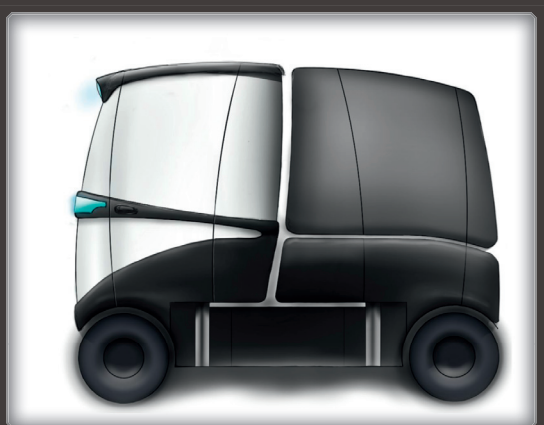
Advanced

Strong

# Evolving

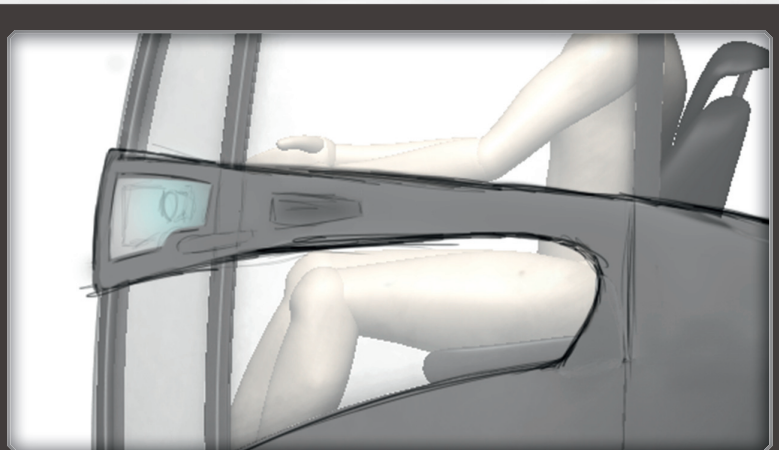
Translating these verbalised qualities into volumes, required an intermediary 2D phase, and a long subsequent aligning and adjusting phase that continues into detailing, in order to approach the values put forth.

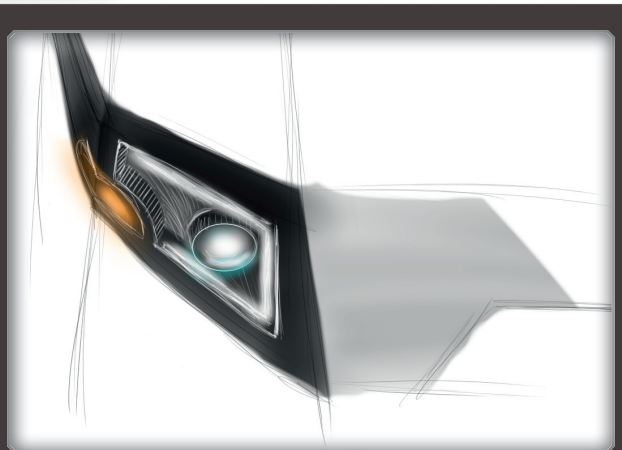
The platform in three segments provides a visual cohesion and the nature of the double articulated steering moves the wheels outward, creating a wide and visually sturdy stance. This coupled with flared wheel arches provides a sense of ruggedness.



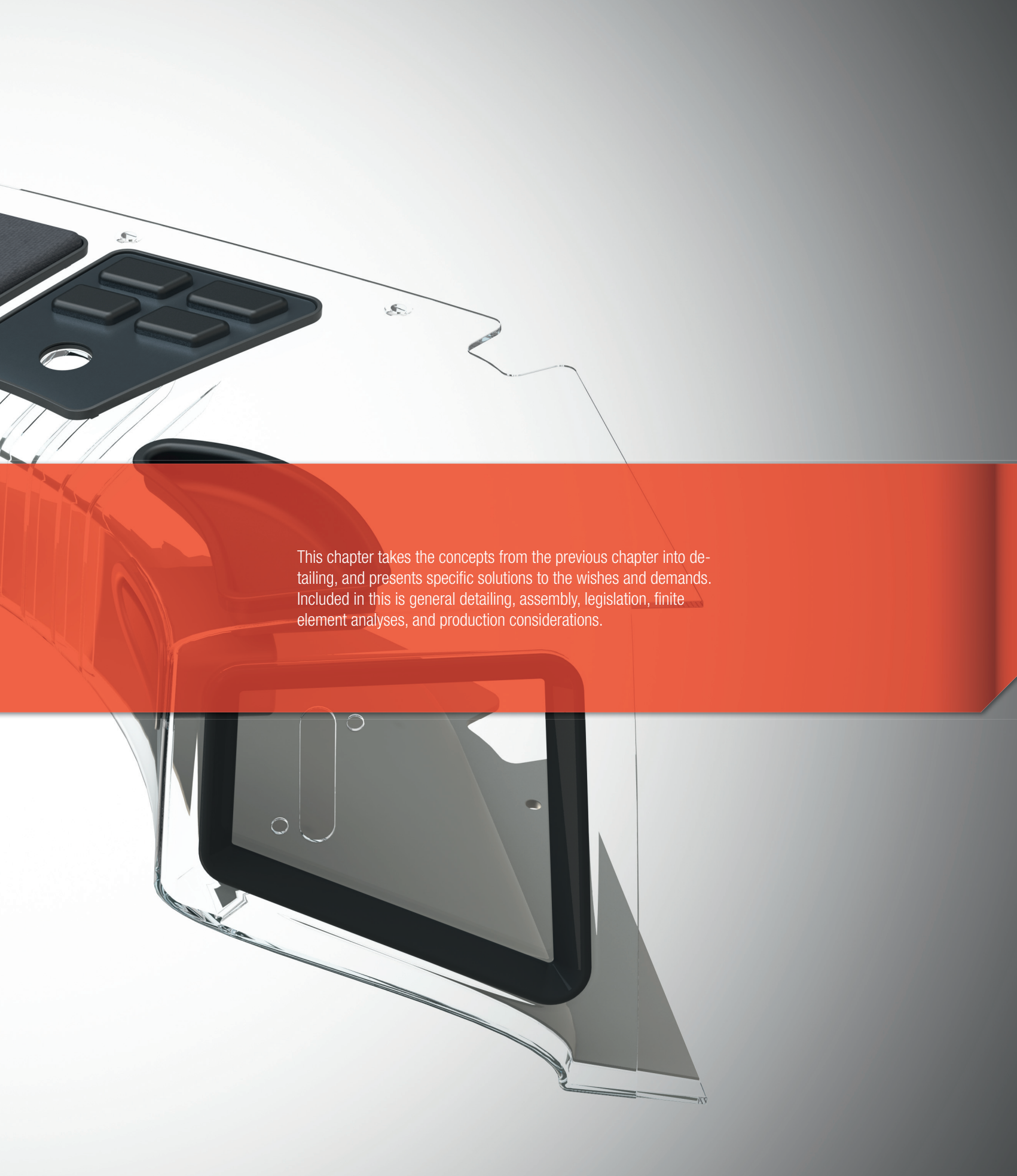
# The face

When drawing and exploring the front of the vehicle and its identity, it becomes very clear that the “eyes”, i.e. head lights, are the single most defining point where the eyes are drawn to. Because of this, and the amount of intention they convey, a lot of effort was put into creating a “friendly”, advanced (i.e. signalling high level of technology such as HID lights and LED daytime running lights as found on modern vehicles), and potent expression.



# DETAILING

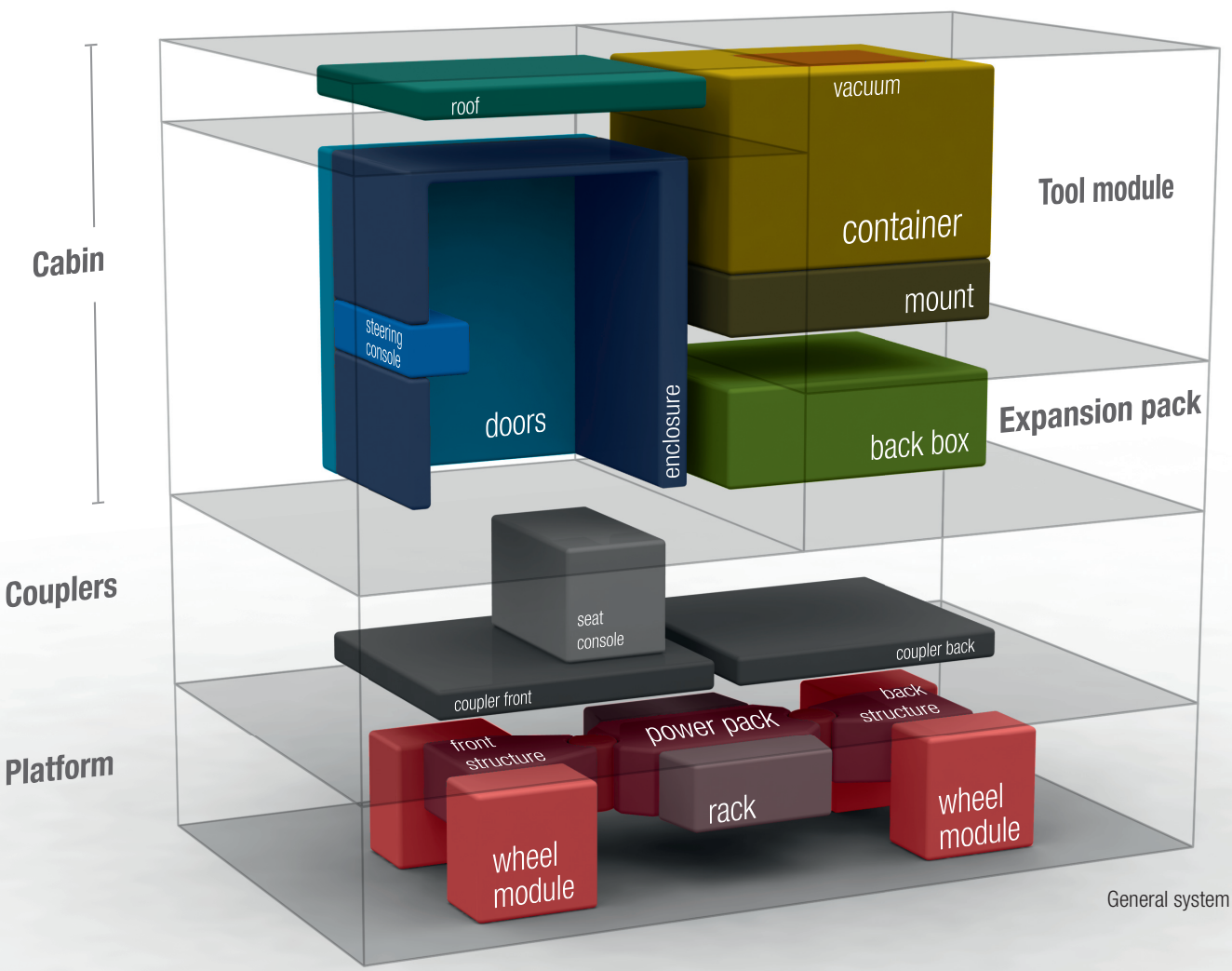


This chapter takes the concepts from the previous chapter into detailing, and presents specific solutions to the wishes and demands. Included in this is general detailing, assembly, legislation, finite element analyses, and production considerations.

# System architecture

## SYSTEM ARCHITECTURE REVISITED

As outlined earlier, the system architecture functions as an overview where separate design challenges are extracted from. In this section a more detailed system architecture map is presented. The detailing phase takes its point of departure from this overview.




General system chunks

# System architecture

## Cabin

### ROOF
- LED strobe light
- Work light
- Interior light
- Radio
- Side view camera
- Ceiling
- Wiper motor

### STEERING CONSOLE
- Structural support
- Soft close module
- Heater
- Adjustability
- Wheel and CANbus
- Trim panel
- Speakers

### ENCLOSURE
- Bodywork
- Glass
- Roll cage
- Door hinge
- Roof mount

### DOORS
- Head lights
- Door open
- Control console
- Glass
- Bodywork
- Structural support
- Hinge

## Tool module

### CONTAINER
- Pipe
- Electric motor
- Vacuum wing
- Box
- Empty hole

### MOUNT
- Water tank
- Slide racks
- Elevation mech
- Structural support
- Hydraulic actuators
- Mount Lock

## Expansion pack

### GENERAL
- Slide racks
- Structural support
- Bodywork
- Vacuum connection
- Lock system
- Bodywork
- water tank

## Coupler front

### GENERAL
- Mudguards
- Floor
- Structural support
- Vibration damper
- Bodywork

### SEAT CONSOLE
- Seat
- Air condition
- Refrigerator
- Storage compartment

## Coupler back

### GENERAL
- Structural support
- Floor
- Mudguards
- Bodywork

## Platform

### FRONT STRUCTURE
- Lift system
- Mouth piece
- Structural support
- Running board
- Hydraulic outlet

### WHEEL MODULE
- Suspension
- Wheels
- Wheel hub
- Brakes

Vacuum flex
Hydro actuators
Joint

### RACKS
- Fuel tank
- BMS
- Hydraulic pump
- Valve block
- Hydraulic reservoir
- Bodywork

### POWER PACK
- Structural support
- Battery pack
- Vacuum channel
- Bodywork

Vacuum angle
Hydro actuators
Joint

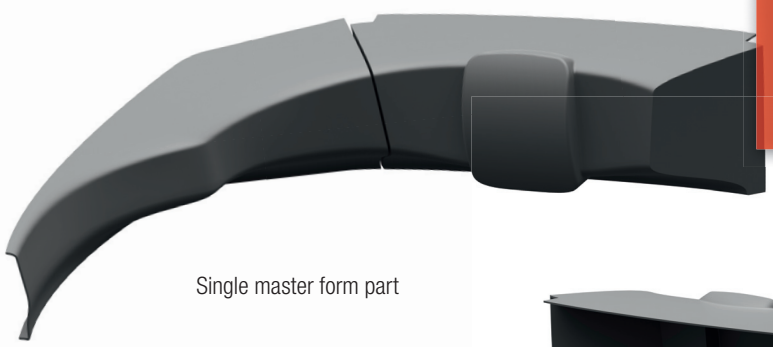
### BACK STRUCTURE
- Structural support
- CV joints
- Gearheads
- Electric motors
- Jet turbine

### WHEEL MODULE
- Suspension
- Wheels
- Wheel hub
- Brakes

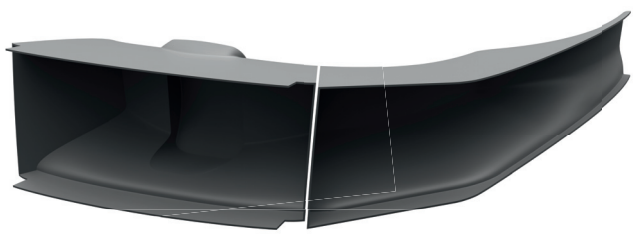
detailed system

# Master form

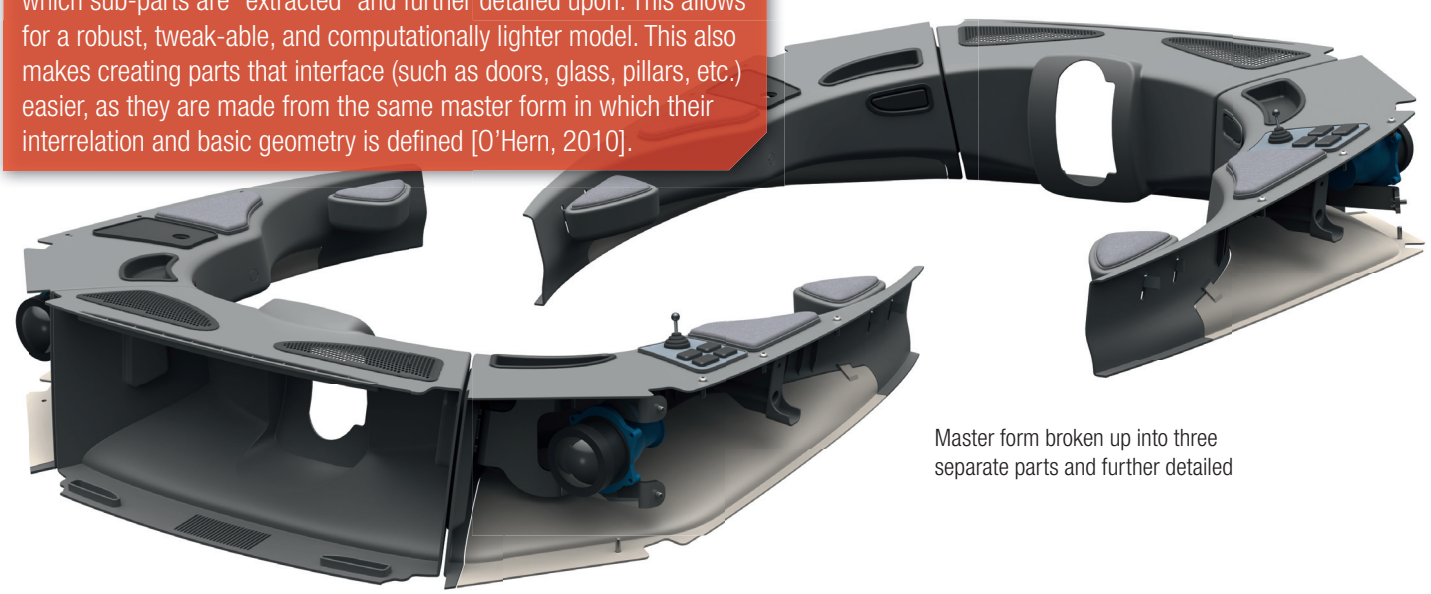
While modelling in 3D CAD can be done in numerous ways, when presented with the complexities of a vehicle, a smarter approach is desirable. Large assemblies where many components, such as bodywork and interior are very interrelated, arise necessitating shared lines and geometries.



Single master form part



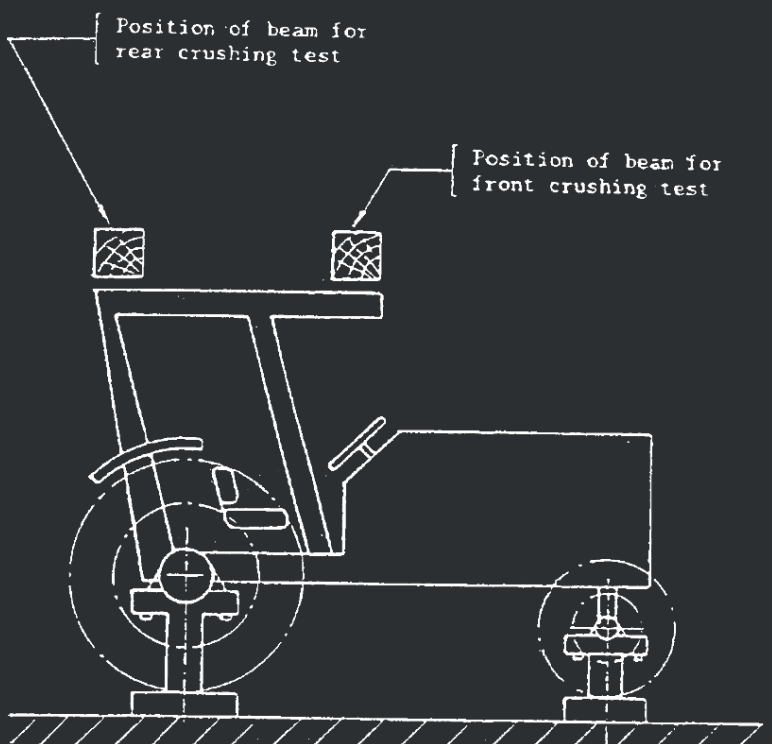
In this project the design team employed what is called master form modelling, where a single part defines the basic geometry, from which sub-parts are “extracted” and further detailed upon. This allows for a robust, tweak-able, and computationally lighter model. This also makes creating parts that interface (such as doors, glass, pillars, etc.) easier, as they are made from the same master form in which their interrelation and basic geometry is defined [O’Hern, 2010].



Master form broken up into three separate parts and further detailed

# Legislation

As with any professional power tool, and indeed vehicles in particular, a comprehensive set of regulations and tests are required to be fulfilled. A tool carrier falls in the tractor category, and as such has a relatively relaxed set of requirements. For the sake of this thesis, two specific regulations are taken into consideration. These are the OECD Code 4 cabin crush test and the Danish Transport Authority regulations regarding placement and types of lighting, and will be illuminated in appropriate sections [OECD, 2012] [DTA 2, 2011].




OECD Crush test setup

# Cabin

## THE CABIN IS DESIGNED AS AN INDEPENDENT MODULE TO BE MOUNTED ON THE PLATFORM.

This allows creating other configurations such an open vehicle. The cabin consists of the roof module, structural cage, pilot bridge, door modules, and bodywork including glass.

### STRUCTURAL CAGE

The function of the structural cage is to prevent the cabin from collapsing in an accident, as well as acting as base frame on which all other components are attached.

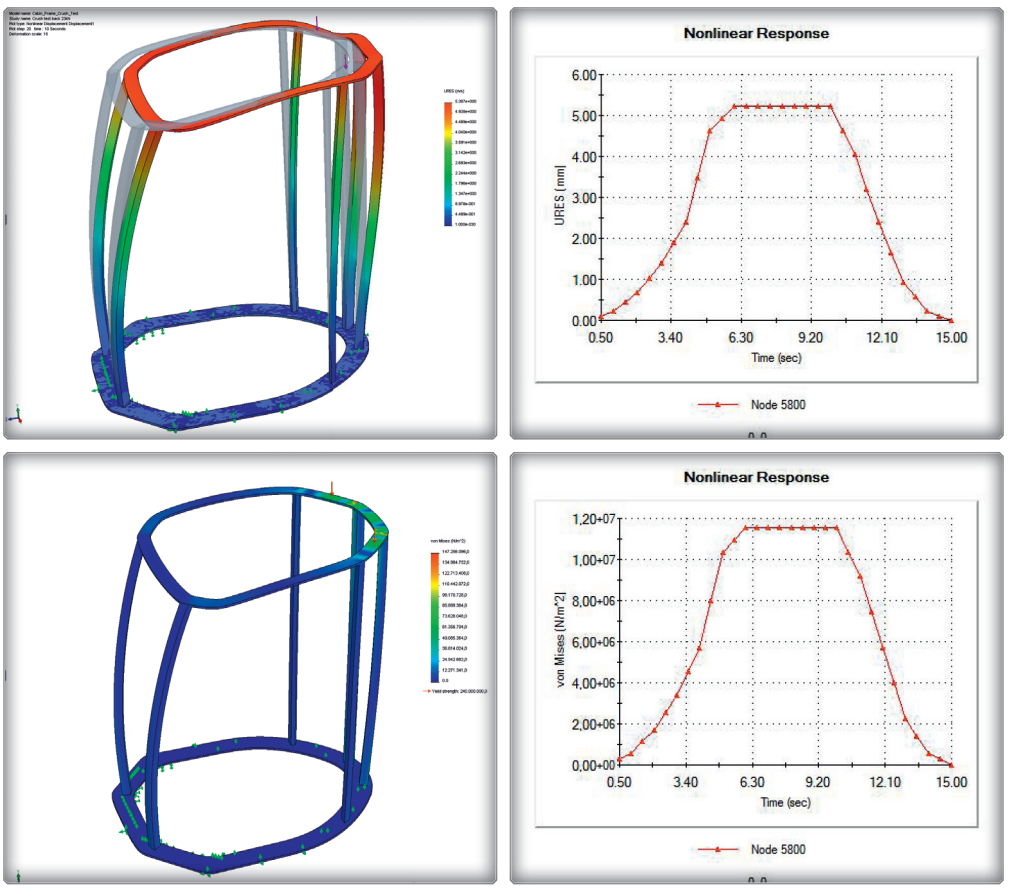

The pillars are made from hard anodised extruded T4 grade 6082 aluminium, CNC bent into required shapes. See appendix G for datasheet.

# Cabin

## CRUSH TEST

As per OECD Code 4, section 3.6.1 and 3.6.2, the design team wishes to test the cage for structural stability. The max weight specification of the VPM 3400 is used. The test is conducted by gradually increasing load until reaching 23kN and retained for 5 seconds. This is done in the front and back as per regulation. See appendix H for Code 4.

Maximum permissible mass: 2000 Kg (taken from VPM 3400)
Reference mass: 1150 Kg (Chosen)
Max/ref ratio: 1,739 (must be under 1.75)
Crush test force: 23.000 N (20x ref. mass in Kg.)




The load results in just above 5 mm of deflection in the back, and stress concentrations do not exceed the yield stress for 6082 T4 of 170 MPa, thus not resulting in permanent deformation. For crush test result in the front see appendix I.

# Roof module

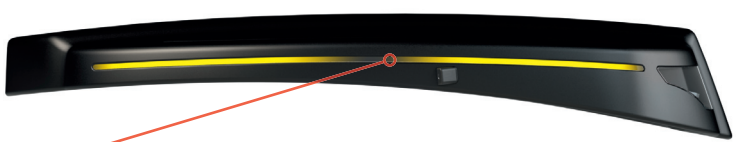
Water deflective creases, ensures rain does not run down the side windows

Wind shield wiper motor

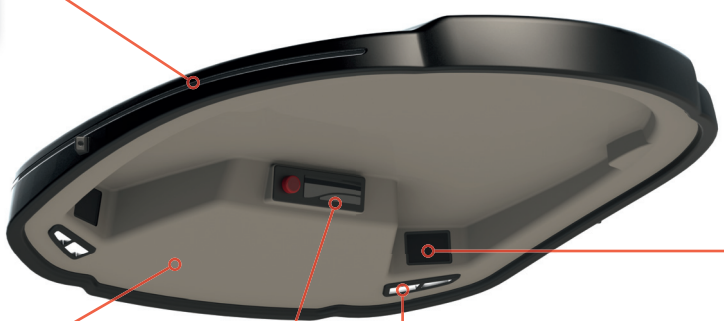
Integrated flush work lights

IP67 Side view cameras

The roof is a single rotation moulded component, where components are mounted into. The inside is lined with a light beige brushed nylon textile to create a warmer and brighter cabin.



Integrated LED strobe bands as beacon lights




Brushed nylon foam lining

Stereo

Cabin lights

Side view monitors

# Pilot bridge

Speaker

Indicator stalks

Steering selection

Door pull

Cup holder

Door release button

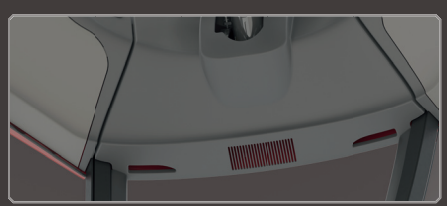
CANbus interaction

Tool controls

Hand rest

Adjustable elbow rest

Dubbed the “pilot bridge”, the band that envelops the user with arm rests, tool controls, and steering wheel, is affixed directly to the cage and doors, integrating many functions into this visually cohesive bridge.



Air circulation vents in the steering console function to de-mist windows. Hot air is provided by a heat exchanger in the steering console and re-uses air from the cabin.

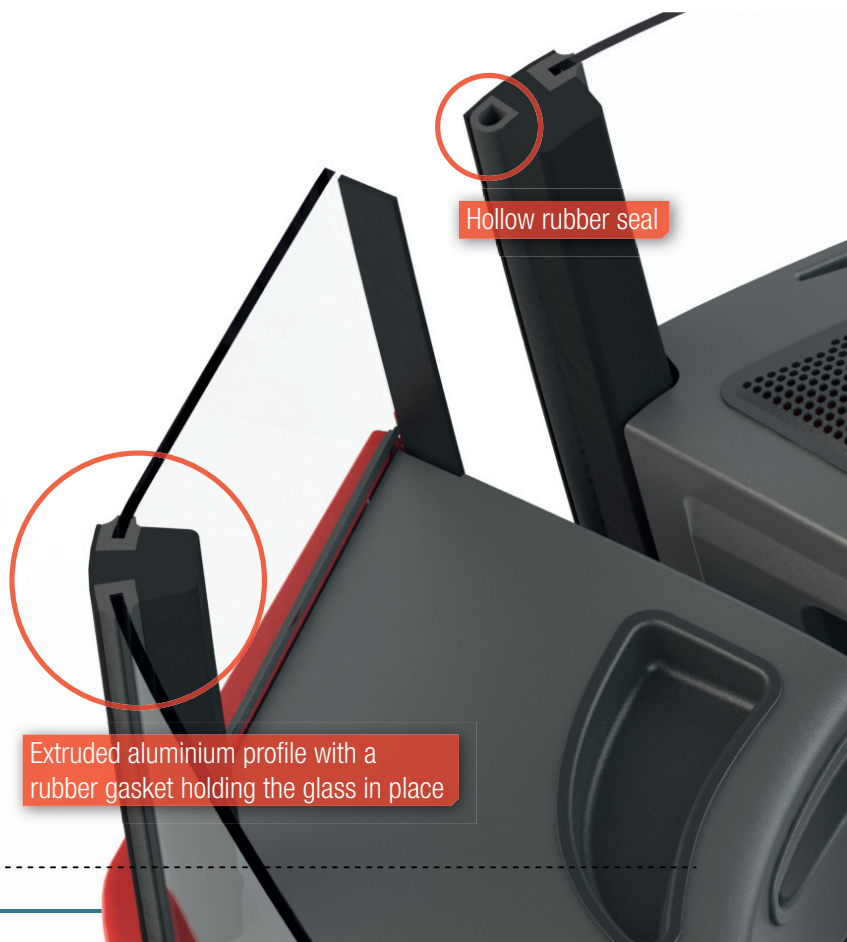
The central steering console houses a strong and very adjustable steering wheel, on the centre of which is an integrated, fixed CANbus computer. This functions as the brains of the machine, interpreting steering, wheel motor speeds, tool motor speeds, and communicating with the battery management system. The CANbus unit also conveys speeds and diagnostic information to the driver.


Stationary CANbus unit

# Door motion

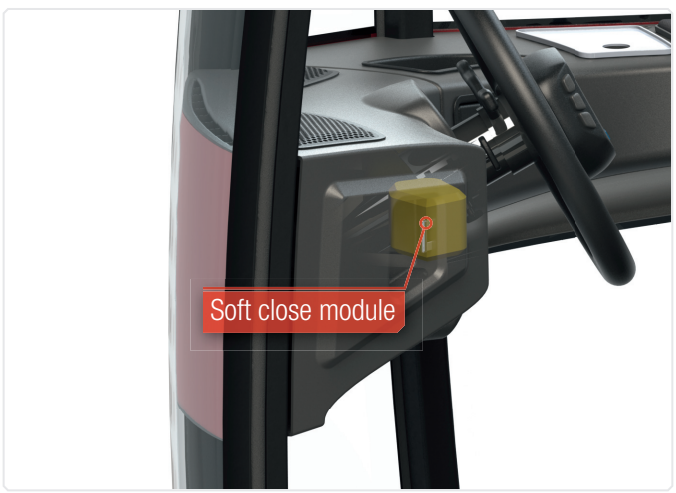
The doors consist of two glass panes held together with an aluminium frame and the plastic door body and are rear hinged to afford greater access. The doors include the head light assembly to create a larger opening. As this project works intensively with aesthetics, it is desirable to have hidden hinges. This is done by creating a double hinged system that closes flush, and opens widely. To help in creating a smooth closing action, the rubber seals are hollow and perforated.

Aluminium door structure



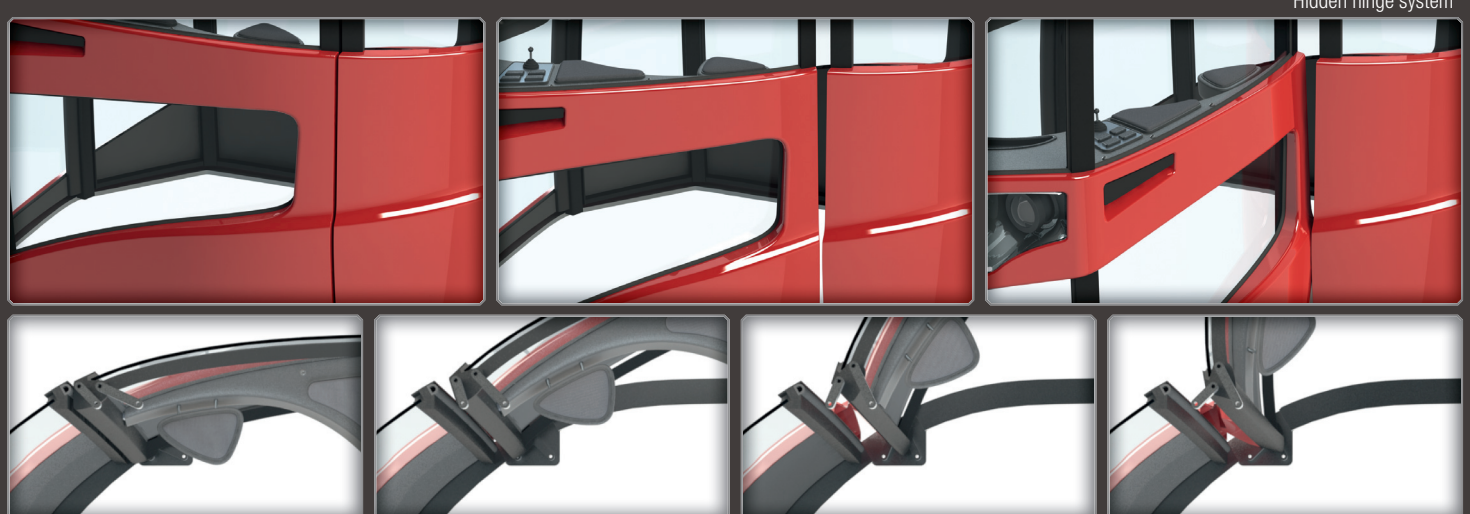
# Door motion

To address the issue of high pressure when closing the doors, the steering console also houses a soft-close system, that catches the door latch as it approaches. A motor then pulls the latch in slowly until fully closed, avoiding that ear-popping slam.



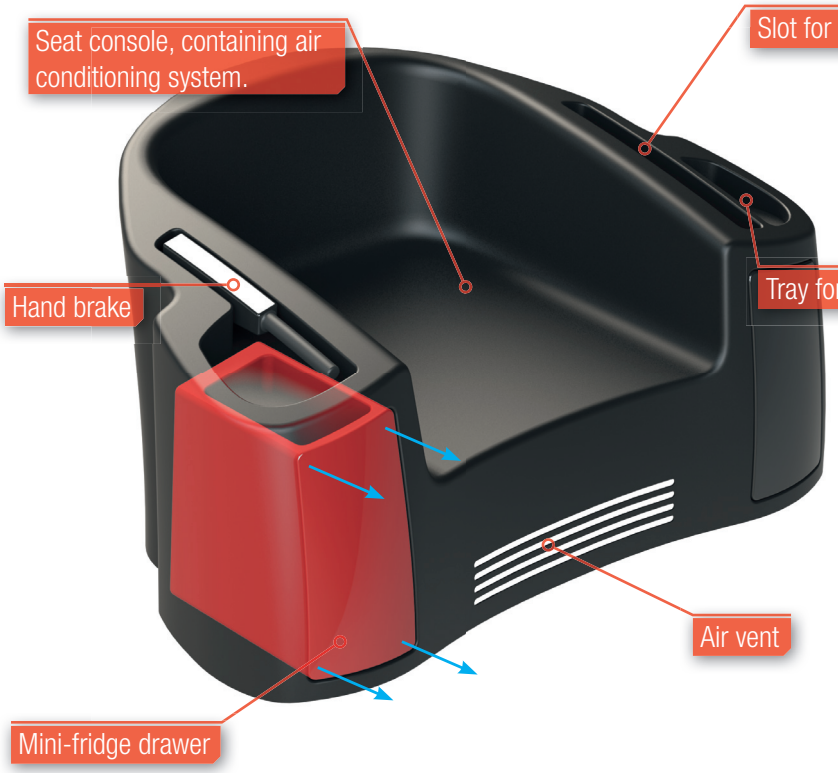


Hidden hinge system



# Seat console

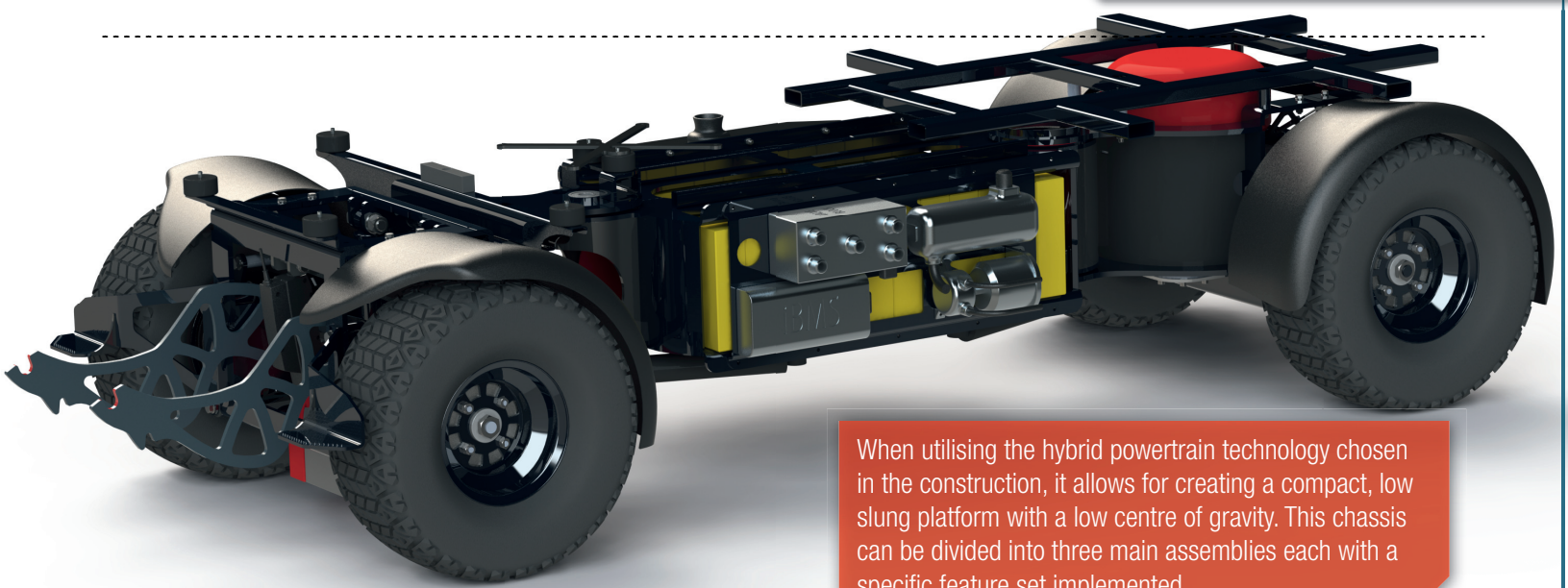
Structurally separate from the cabin, the seat console houses storage compartments, a small fridge, a hand brake, and the air conditioning system while still allowing plenty of space for legs and feet. This is possible due to the completely flat floor, resulting in extra space.





The Grammer Compacto M seat is selected because of its compact size, air suspension with compressor, and reputation for excellence.
The seat used is specified without arm rests (an optional extra), as these are incorporated into the doors.

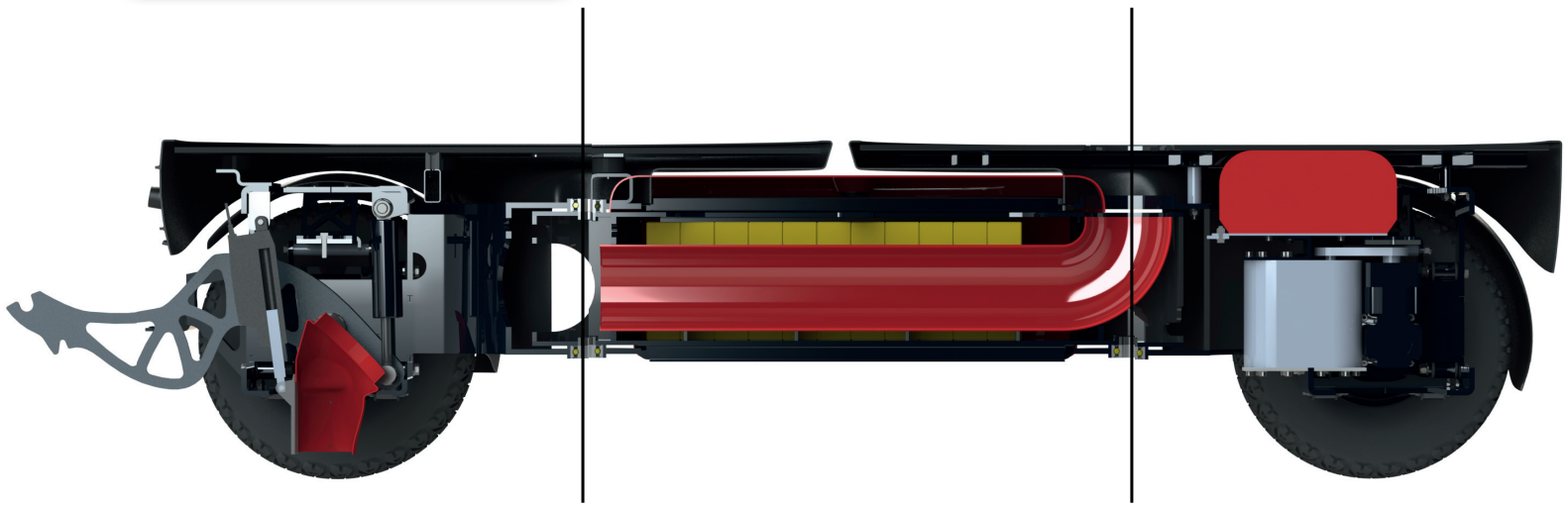
# Chassis & platform



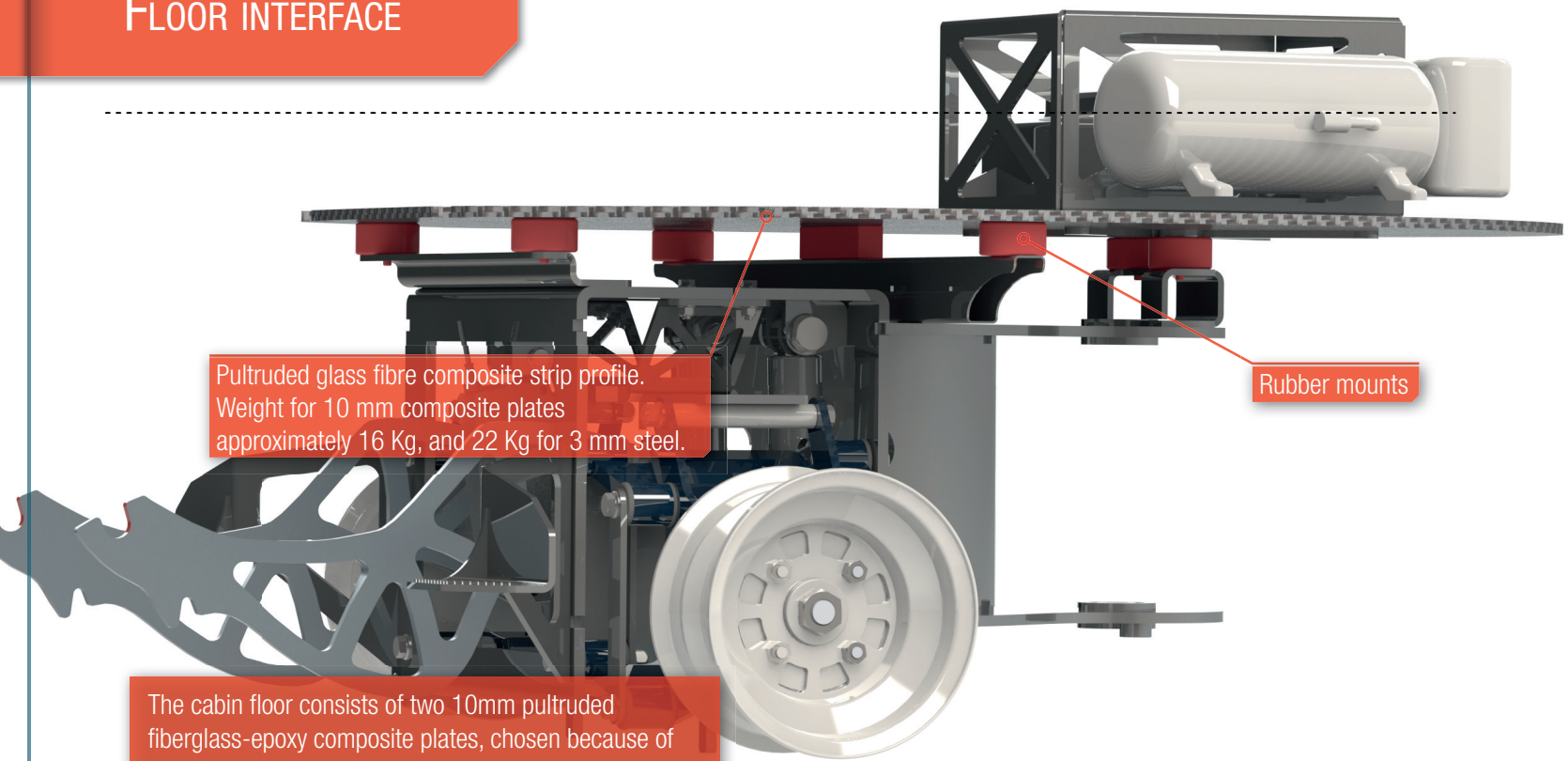
When utilising the hybrid powertrain technology chosen in the construction, it allows for creating a compact, low slung platform with a low centre of gravity. This chassis can be divided into three main assemblies each with a specific feature set implemented.

The front holds, apart from suspension, the lift arms, an integrated mouth piece, tool interface, and a running board. The centre section houses the batteries, BMS (battery management system), fuel tank, vacuum pipe, and hydraulics. The rear section houses the jet turbine and the electric motors with gearing.

**COMPONENTS ARE INTEGRATED INTO THE PLATFORM FROM THE VERY BEGINNING**

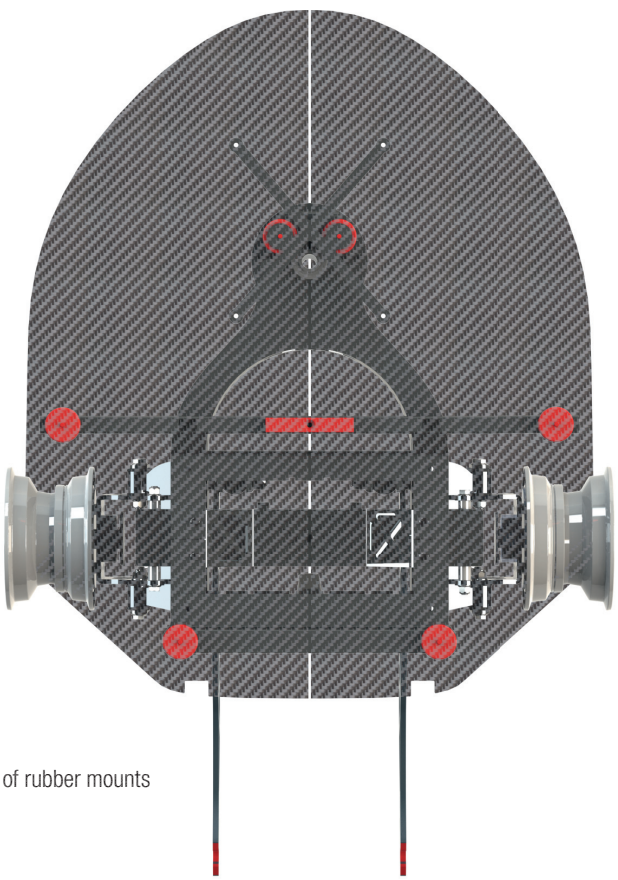


# Floor interface




The cabin floor consists of two 10mm pultruded fiberglass-epoxy composite plates, chosen because of strength, weight, and vibration reduction properties, as compared to steel plate. The floor is attached to the chassis via a series of rubber suspension mounts to reduce transmitted vibrations.

Sample of pultruded composite from FiberLine Composites - feels very rigid, even when bent perpendicular to the pultrusion direction. Has an E modulus in the pultrusion direction of 17 GPa. [Fiberline, 2012]

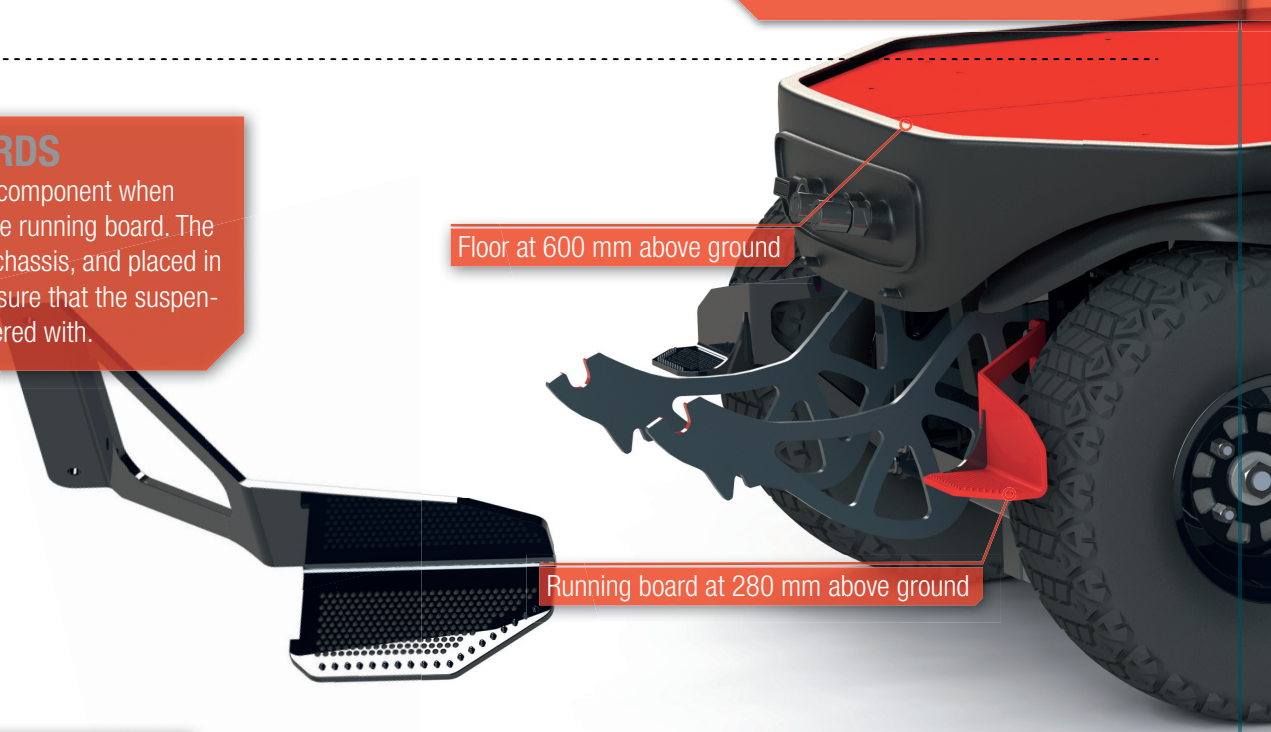


Overview of rubber mounts

# Suspension & boarding

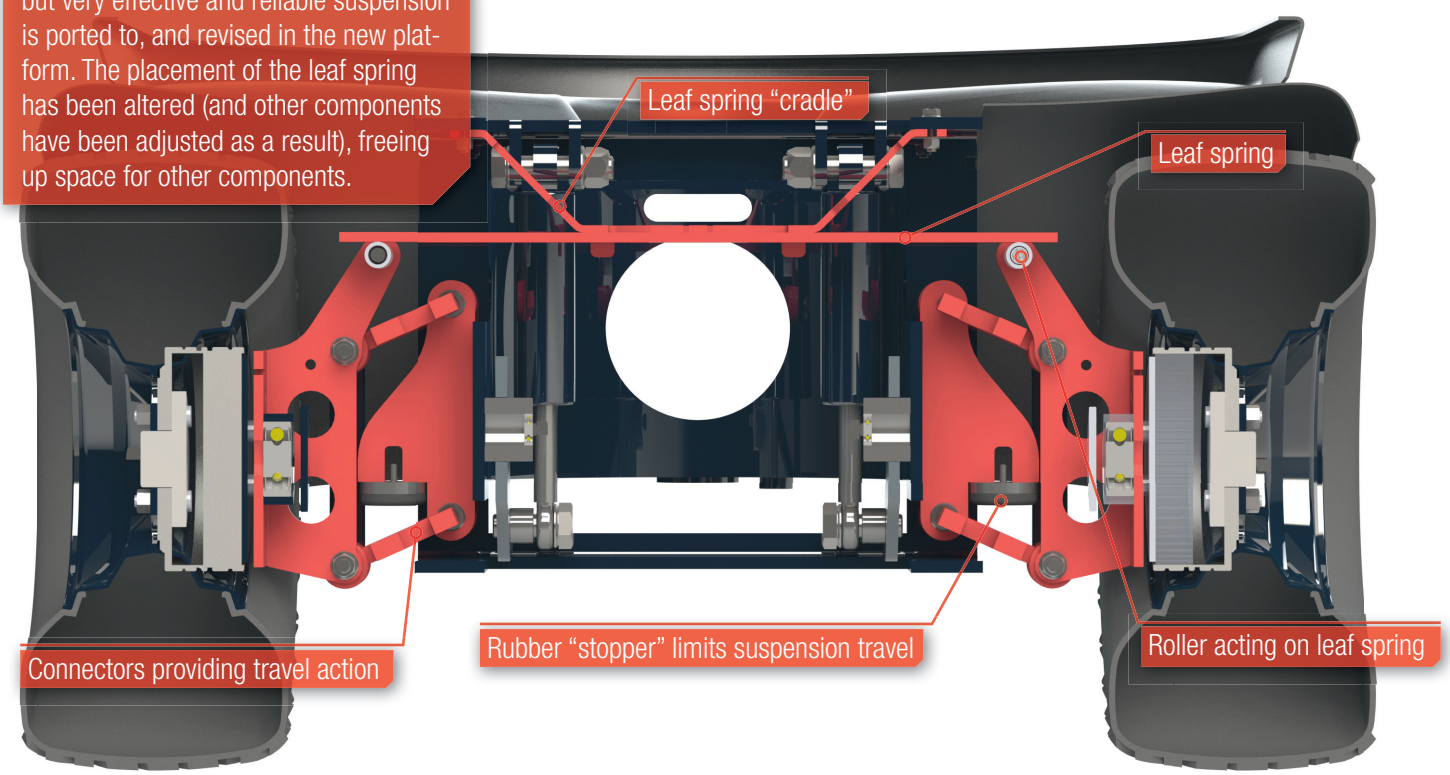
## RUNNING BOARDS

A simple, but essential component when entering the cabin, is the running board. The step is bolted onto the chassis, and placed in front of the wheel to ensure that the suspension action is not interfered with.

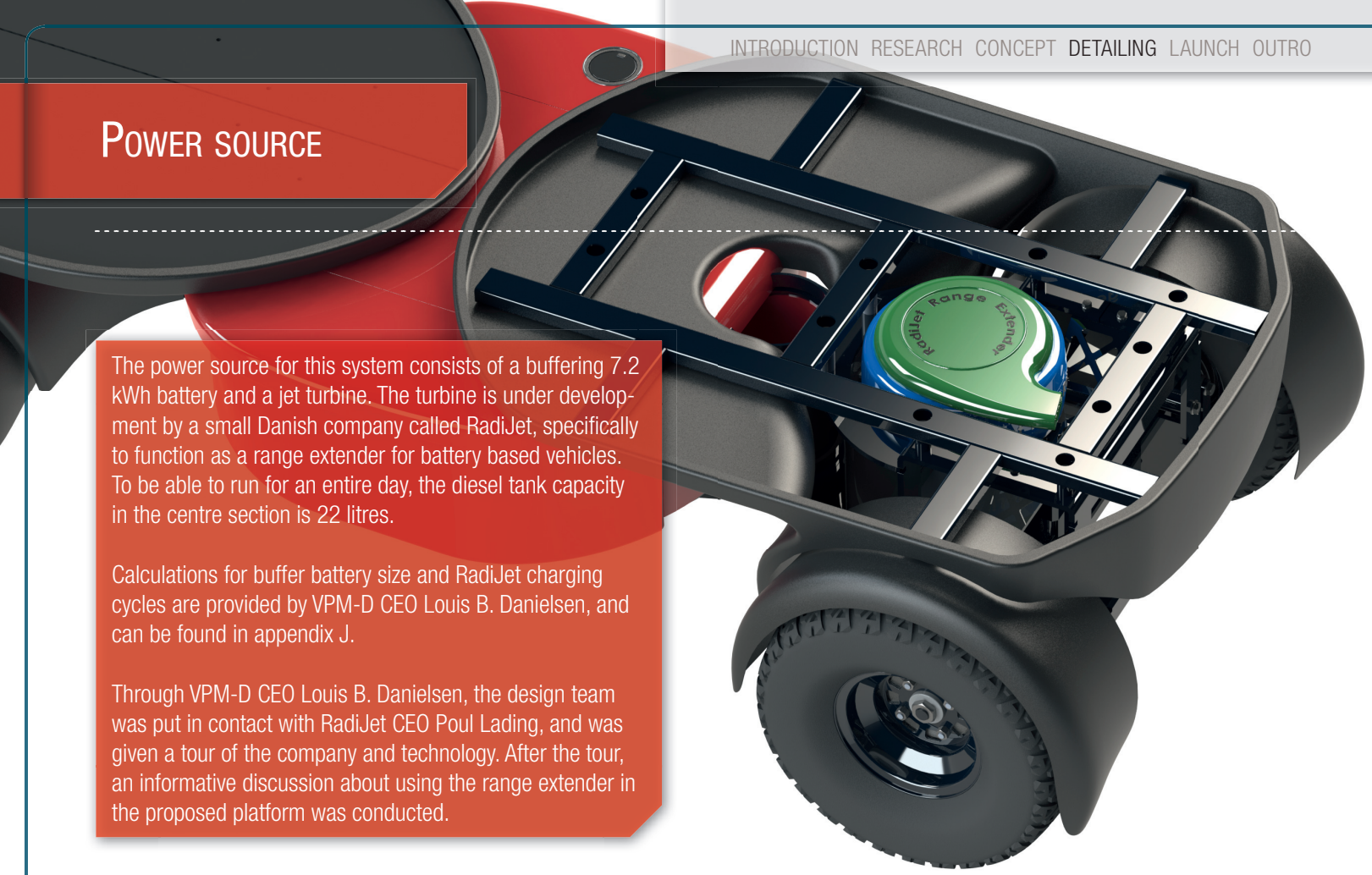



## ADAPTING SUSPENSION

A legacy from the VPM 3400, the simple but very effective and reliable suspension is ported to, and revised in the new platform. The placement of the leaf spring has been altered (and other components have been adjusted as a result), freeing up space for other components.



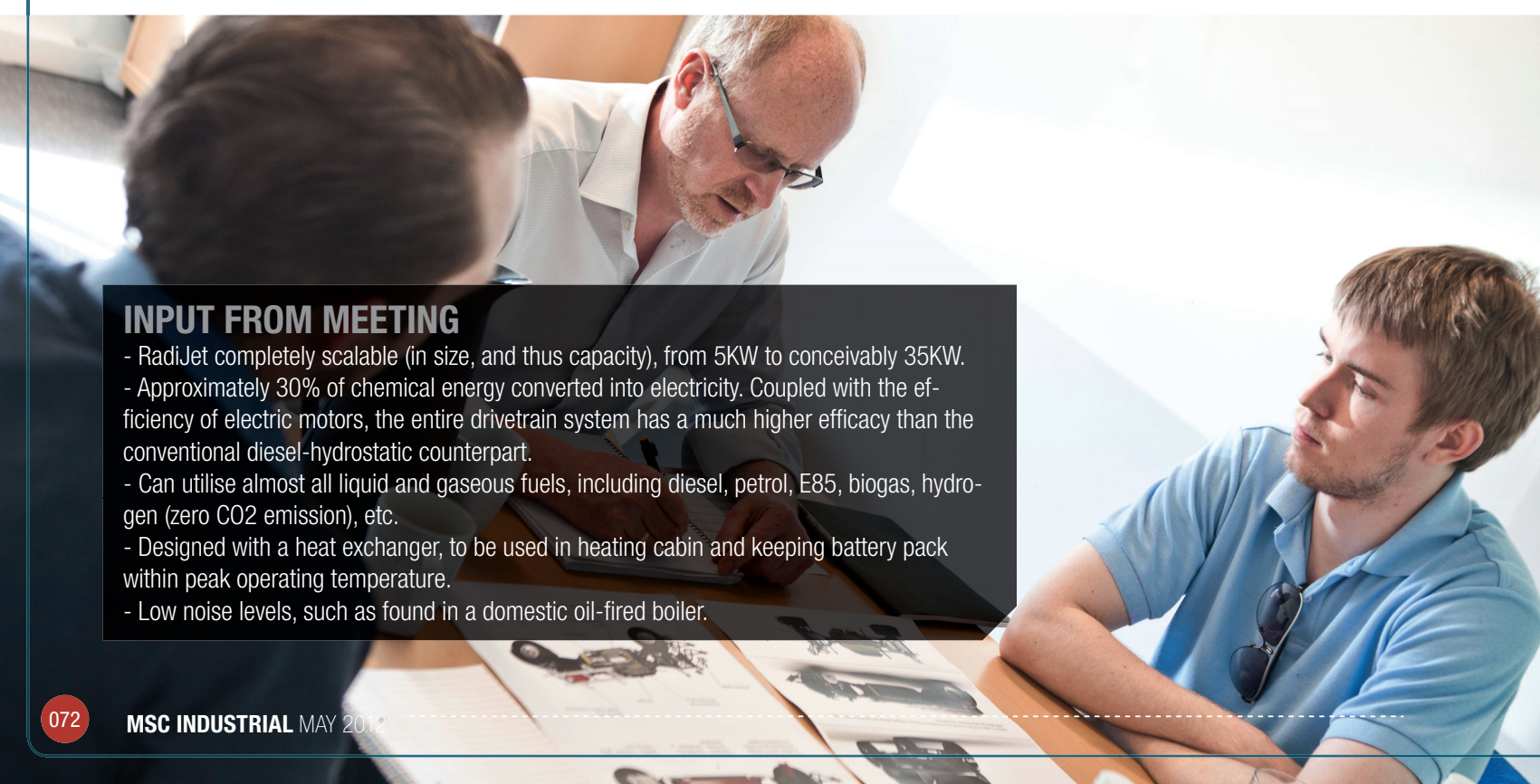
# Power source




The power source for this system consists of a buffering 7.2 kWh battery and a jet turbine. The turbine is under development by a small Danish company called RadiJet, specifically to function as a range extender for battery based vehicles. To be able to run for an entire day, the diesel tank capacity in the centre section is 22 litres.

Calculations for buffer battery size and RadiJet charging cycles are provided by VPM-D CEO Louis B. Danielsen, and can be found in appendix J.

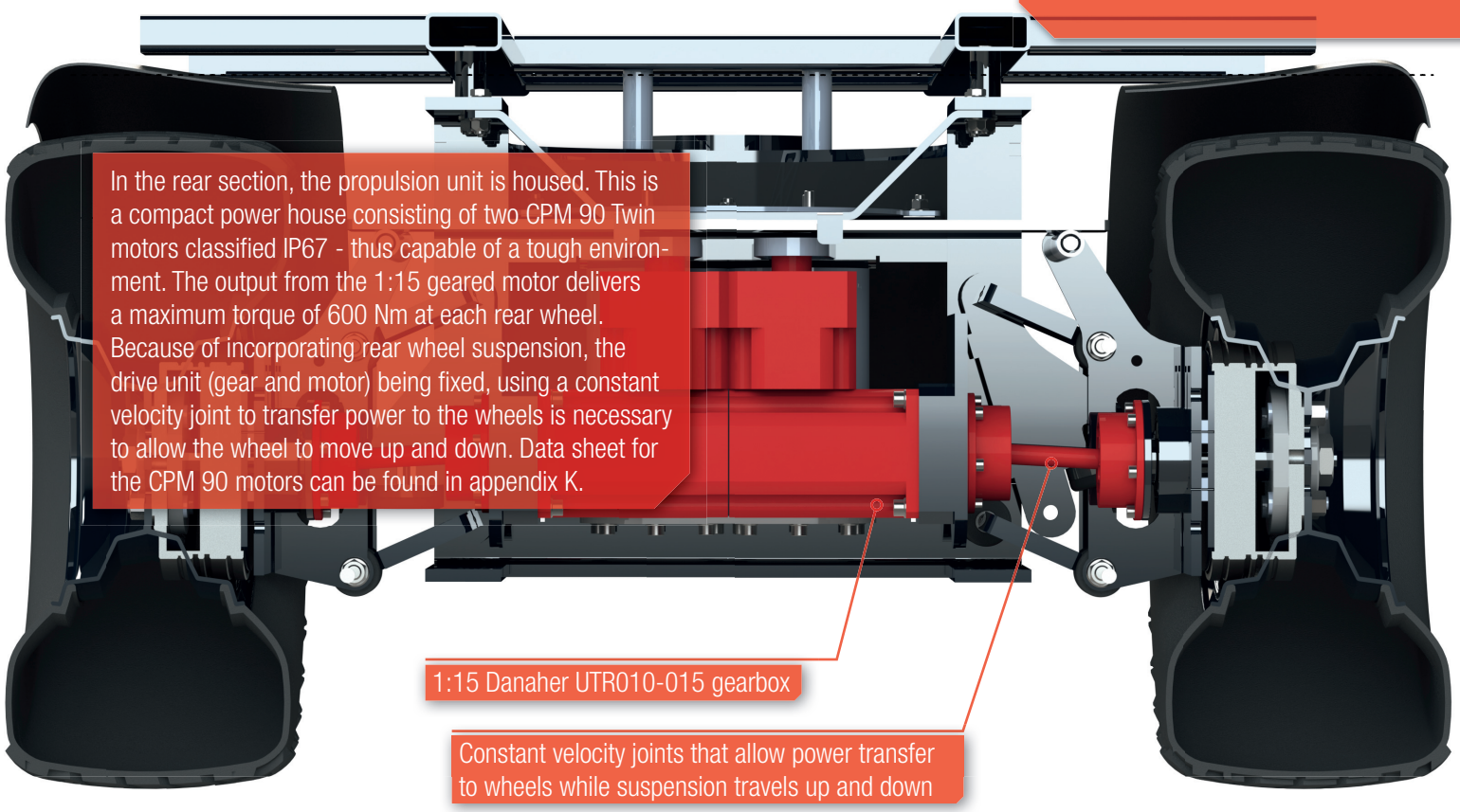
Through VPM-D CEO Louis B. Danielsen, the design team was put in contact with RadiJet CEO Poul Lading, and was given a tour of the company and technology. After the tour, an informative discussion about using the range extender in the proposed platform was conducted.



## INPUT FROM MEETING

- RadiJet completely scalable (in size, and thus capacity), from 5KW to conceivably 35KW.
- Approximately 30% of chemical energy converted into electricity. Coupled with the efficiency of electric motors, the entire drivetrain system has a much higher efficacy than the conventional diesel-hydrostatic counterpart.
- Can utilise almost all liquid and gaseous fuels, including diesel, petrol, E85, biogas, hydrogen (zero CO2 emission), etc.
- Designed with a heat exchanger, to be used in heating cabin and keeping battery pack within peak operating temperature.
- Low noise levels, such as found in a domestic oil-fired boiler.

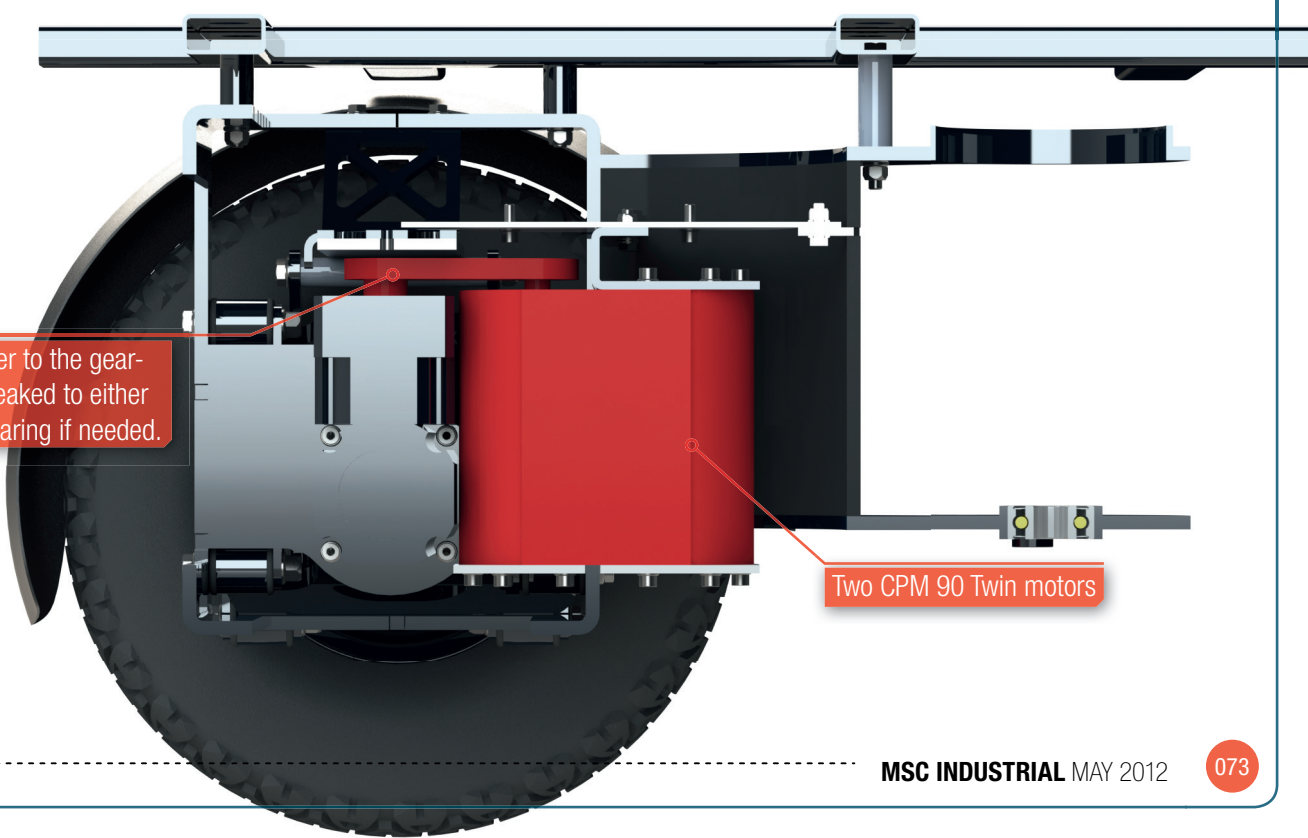
# Drivetrain



In the rear section, the propulsion unit is housed. This is a compact power house consisting of two CPM 90 Twin motors classified IP67 - thus capable of a tough environment. The output from the 1:15 geared motor delivers a maximum torque of 600 Nm at each rear wheel. Because of incorporating rear wheel suspension, the drive unit (gear and motor) being fixed, using a constant velocity joint to transfer power to the wheels is necessary to allow the wheel to move up and down. Data sheet for the CPM 90 motors can be found in appendix K.

1:15 Danaher UTR010-015 gearbox

Constant velocity joints that allow power transfer to wheels while suspension travels up and down



Belt drives transfer power to the gearboxes. These can be tweaked to either increase or decrease gearing if needed.

Two CPM 90 Twin motors

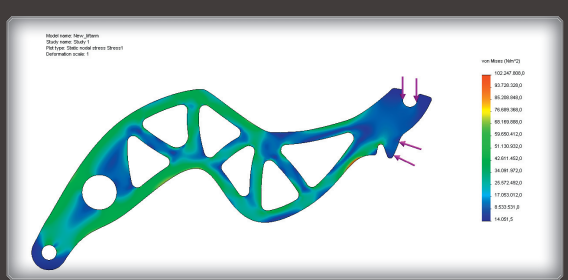
# New lift arms

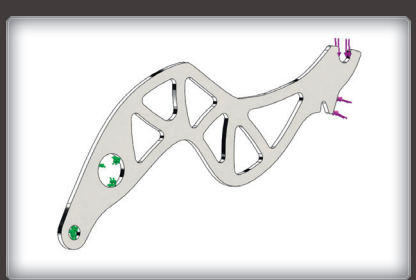
The lift arms have been redesigned to fit into a new chassis constellation, while retaining the VPM 3400 interface and thus tool mount compatibility.

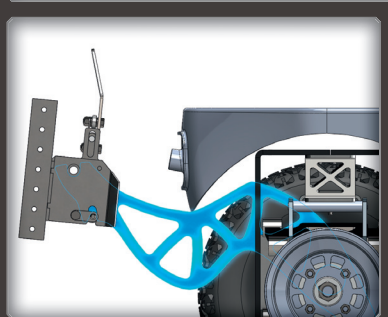
To aid in aligning the lift arms with the tool interface, the grips are painted red, and a set of LEDs illuminate them in dark conditions.

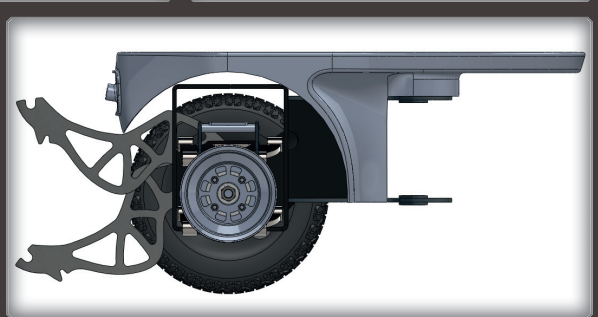
These new lift arms have been optimised through iterations via finite element analyses to ensure reduced stress concentrations. The FEA test conducted is of the static type, assuming a tool weight of approximately 200 Kg (2000 N) and a dynamic factor of 3, returning a peak load of 6000 N (3000 N per arm). In the final configuration of the lift arm, the analysis returned a maximum yield stress of 102 MPa. The selected material, Hardox, has a yield strength of 1200 MPa, giving a factor of safety of 12.

While this might seem excessive, the lift arms have a hard life under the chassis with constant dynamic loads, vibrations, abuse, scratches, and are exposed to humidity, corrosion, and varying temperatures.









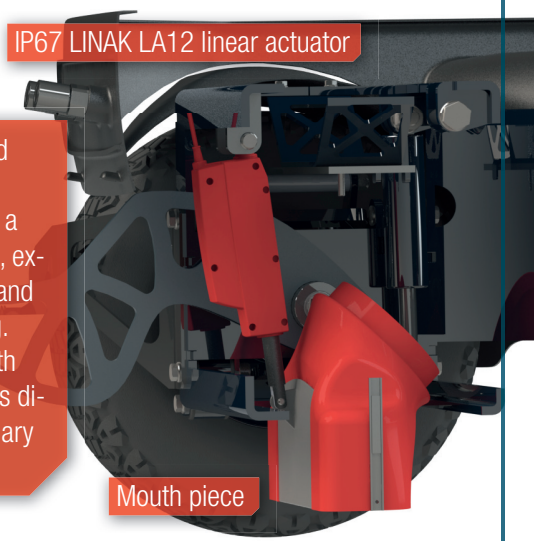
The new lift arms interfacing with the current tool interface.

The two extreme positions of the arms.

# Integrated vacuum

As mentioned, the street sweeper is a very popular tool, and as such, it is appropriate to incorporate some functionality into the machine to heighten performance and avoid cumbersome solutions.

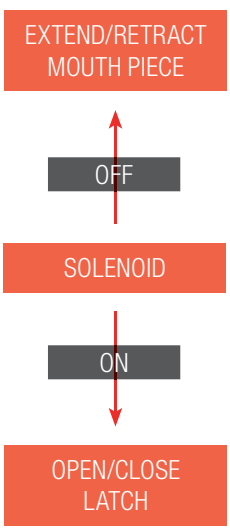
As an alternative to integrating the street sweeper mouth piece in the front sweeper, it is here affixed to the front chassis. This greatly simplifies the construction of the front sweeper attachment as no considerations has to be given to connecting, sealing, and aligning the vacuum pipe or aligning the mouth piece to the ground while sweepers follow the contours. This also allows for the perspective of a grass collection while having the lawn mower tool attached.




The mouth piece is designed with three operating modes facilitated by a solenoid and a linear actuator, i.e. retracted, extended with small opening, and extended with large opening. The large opening (along with the following vacuum pipe) is dimensioned to allow an ordinary wine bottle to pass.

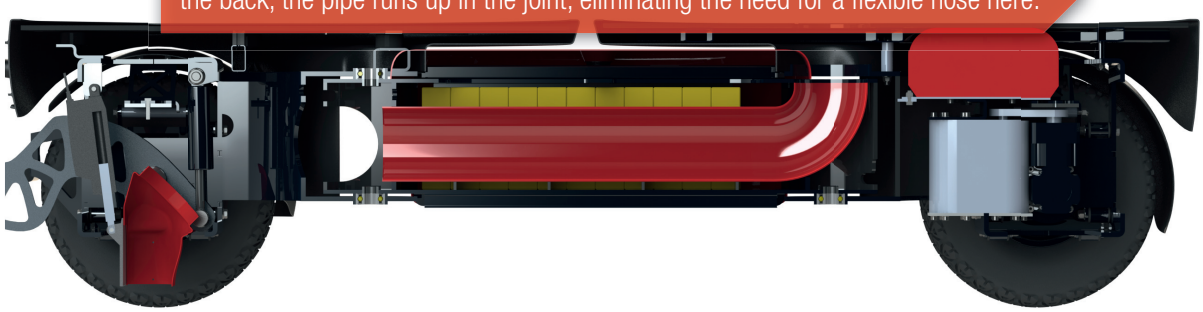
Retracted and extended mouth piece.

Mouth piece with narrow and large opening. A rubber skirt is attached at the bottom.



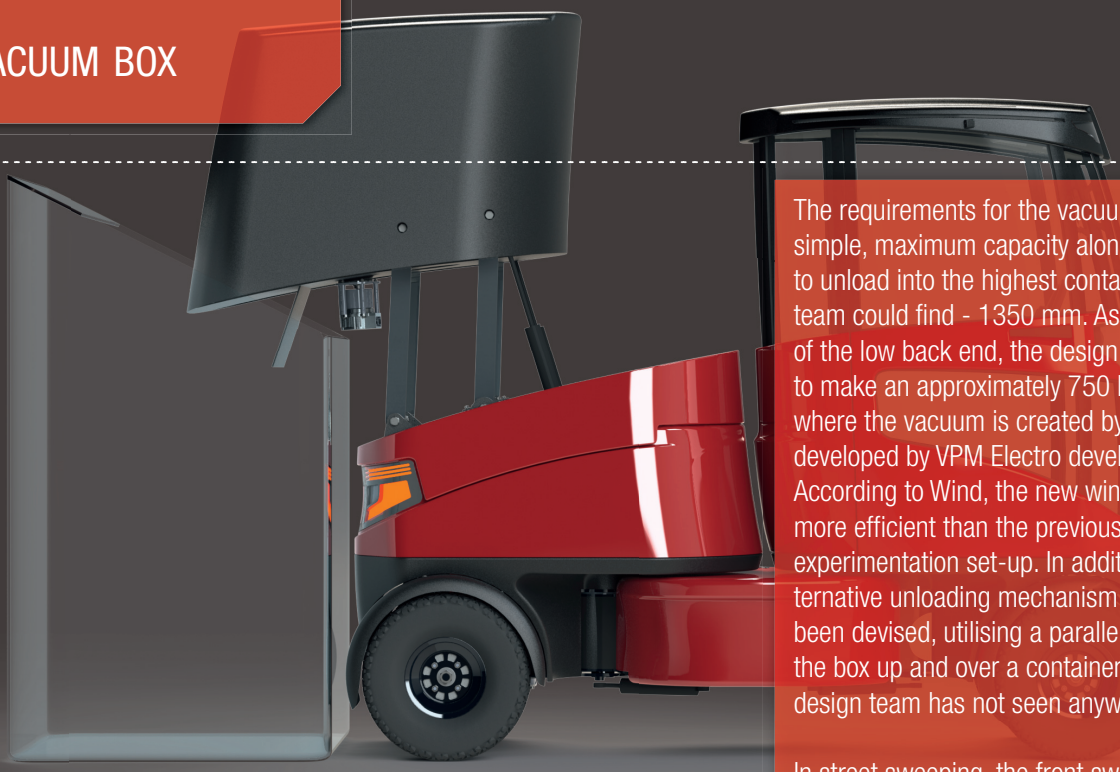

The vacuum pipe is routed through the centre of the base, and is made structurally integral for added stability of the platform. Using pipes instead of flexible hoses as much as possible, has the added benefit of significantly reduced drag, resulting in less pressure loss, and hence either more powerful vacuum, lower power consumption, or a combination.

The mouth piece connects to the rigid pipe with a flexible hose. This hose also provides the flexibility that allows the vacuum channel to run through the front joint. At the back, the pipe runs up in the joint, eliminating the need for a flexible hose here.



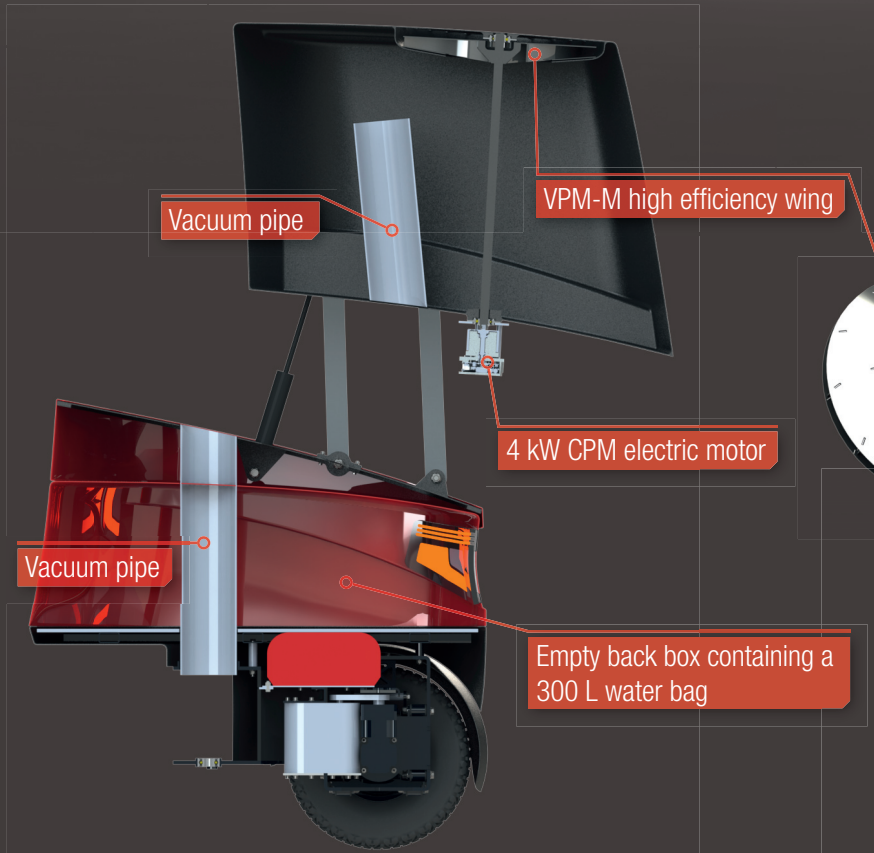
Example of flexible hose, currently used all the way from the mouth piece to the vacuum box.

# Vacuum box

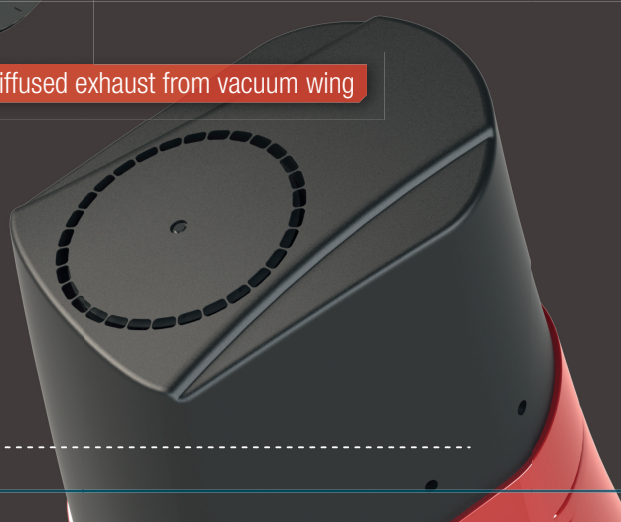


The requirements for the vacuum box are quite simple, maximum capacity along with being able to unload into the highest container the design team could find - 1350 mm. As such, because of the low back end, the design team was able to make an approximately 750 litre vacuum box, where the vacuum is created by a cyclone wing developed by VPM Electro developer Bjarne Wind. According to Wind, the new wing is four times more efficient than the previous VPM wing in his experimentation set-up. In addition to this, an alternative unloading mechanism to the current has been devised, utilising a parallelogram to move the box up and over a container - an approach the design team has not seen anywhere else.

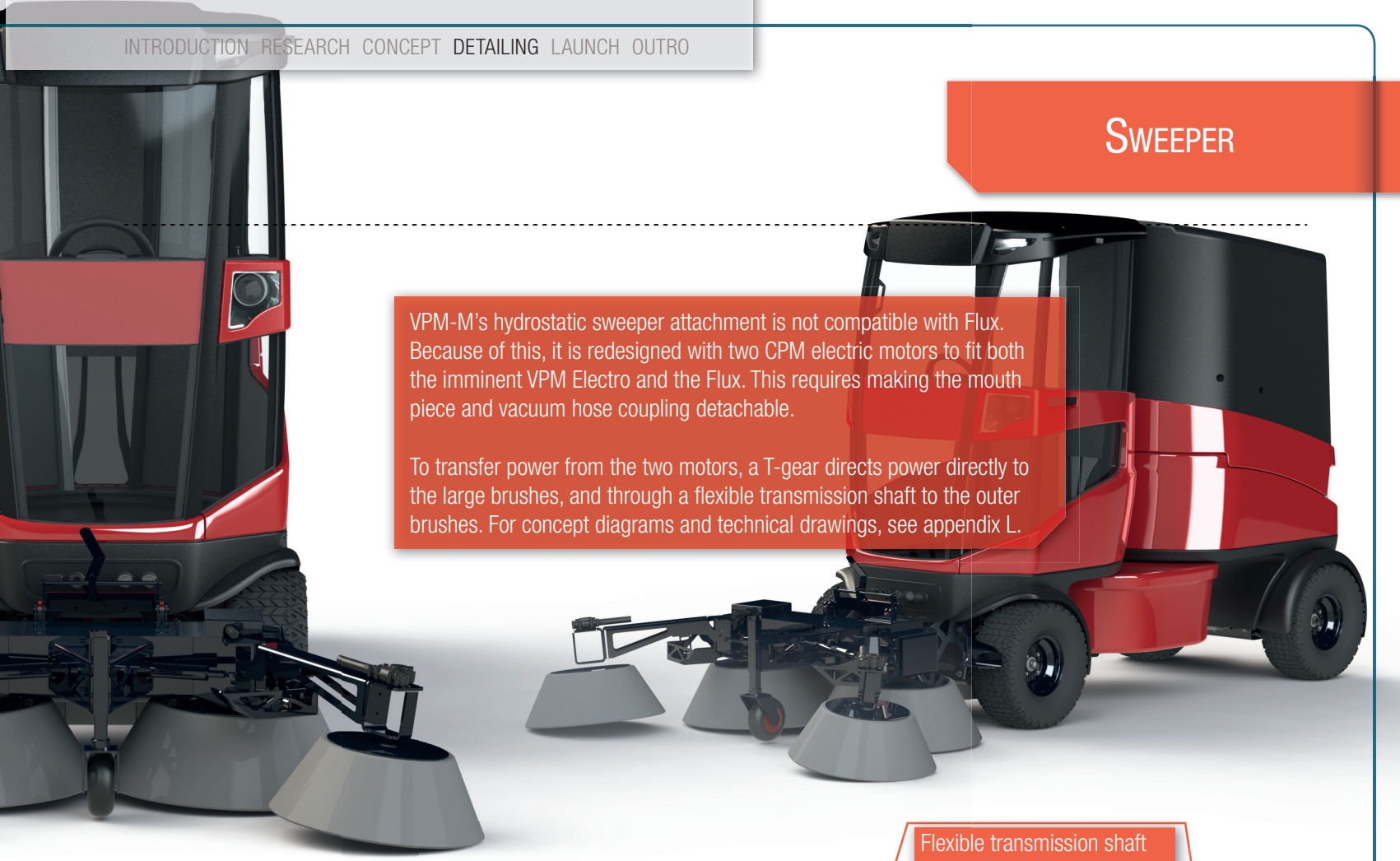
In street sweeping, the front sweepers often have sprinklers attached. This is done to prevent dust from swirling up and escape the grasp of the mouth piece. Conventionally, a water tank is included in the vacuum box's volume to provide for this need. In this machine, a 300 litre water bag easily fits into the lower back box, not compromising the 750 litre capacity while securing a lower centre of gravity.




Diffused exhaust from vacuum wing

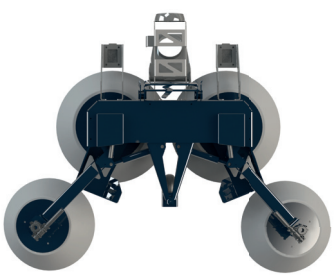


# Sweeper

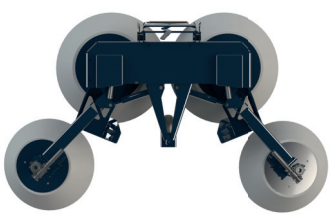


VPM-M's hydrostatic sweeper attachment is not compatible with Flux. Because of this, it is redesigned with two CPM electric motors to fit both the imminent VPM Electro and the Flux. This requires making the mouth piece and vacuum hose coupling detachable.

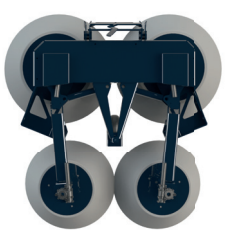
To transfer power from the two motors, a T-gear directs power directly to the large brushes, and through a flexible transmission shaft to the outer brushes. For concept diagrams and technical drawings, see appendix L.



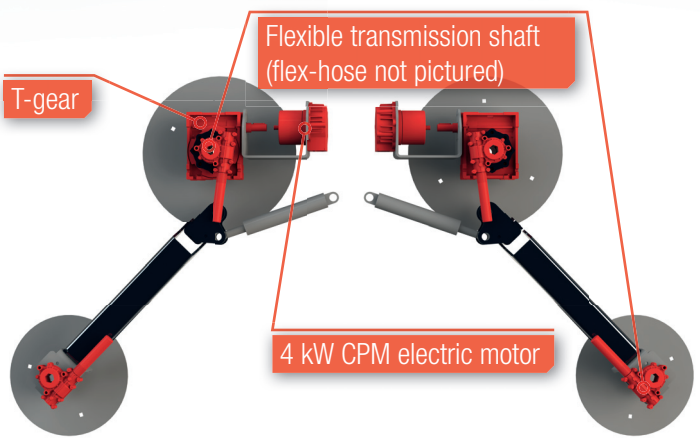
Electric sweeper with VPM Electro attachment (back wheels for vacuum hose alignment and mouth piece)



Electric sweeper compatible with Flux



The two sweeper arms can be independently flipped in and out




As an exercise in simplicity, two-brush sweeper concept with a single plastic bridge and central water jets was developed. Much lighter, simpler, and easier to handle, this attachment also has a less cluttered and calm appearance.

# The bodywork

Creating a cohesive and aesthetically functioning bodywork has been a challenge throughout the detailing process. This spread highlights some thoughts. The coloured panels are to be made of sheet plastic, vacuum formed into the desired shapes.

One of the wishes was to create a handsome, yet rugged machine, that would not seem too delicate to tangle with mud. To this affect chunky, exposed tires are matched with flared wheel arches that struts out from a lower, dark matte base.

To create a seemingly strong cabin, the cage made from relatively wide profiles and hard anodised, giving a dulled surface finish. This creates a less delicate expression.

The pilot band that stands out from the glass panes, very much helps to visually stabilise the pillars.

The line created by the platform is accentuated by the middle section that seeks to create a cohesion that binds the segments together into a single machine. This was a distinctive goal as the design team felt that articulated steering in tool carriers has a tendency to create a broken and visually weak joint.

# The bodywork

Almost all lines have a tendency to converge in the “nose” of the machine, where the tool interface is located, creating a sense of direction and calm. One exception to this is the pilot band that has its own life, as this is the where the “eyes” and focal point of the face of the machine is located.

The shoulders of the vehicle run in an arc from the front to the back and is created by a crease on the bodywork. This arc works in concert with the wide wheel base, to create a wide and secure stance.

# Lights

Daytime running lights

Low beam

Indicators

As mentioned, the head light is the focal point in creating a face for the machine. The head lamps have been styled to look both friendly and strong. At the same time the design team chose to utilise 90 mm Hella Xenon HID units providing a modern, high tech appearance. See appendix M for data sheet.

Generally, the requirements for lighting in a tractor are very relaxed. This has made these regulations easy to comply with, especially because of the automotive inspiration, where the demands are much higher. For the relevant sections of the Danish Transport Authority, see appendix N.

Headlights
A tractor requires only one low beam head light. This / these should be placed no higher than 150 cm from ground level, and no lower than 60 cm.

The Hella asymmetric xenon head lamps placed at 129 cm above ground level and complies with the directives.

Daytime Running lights
Daytime running lights are not mandatory on the front of a tractor, however when they are present, they must be no higher than 190 cm above ground level, and be visible at least 10 degrees inward and downward.

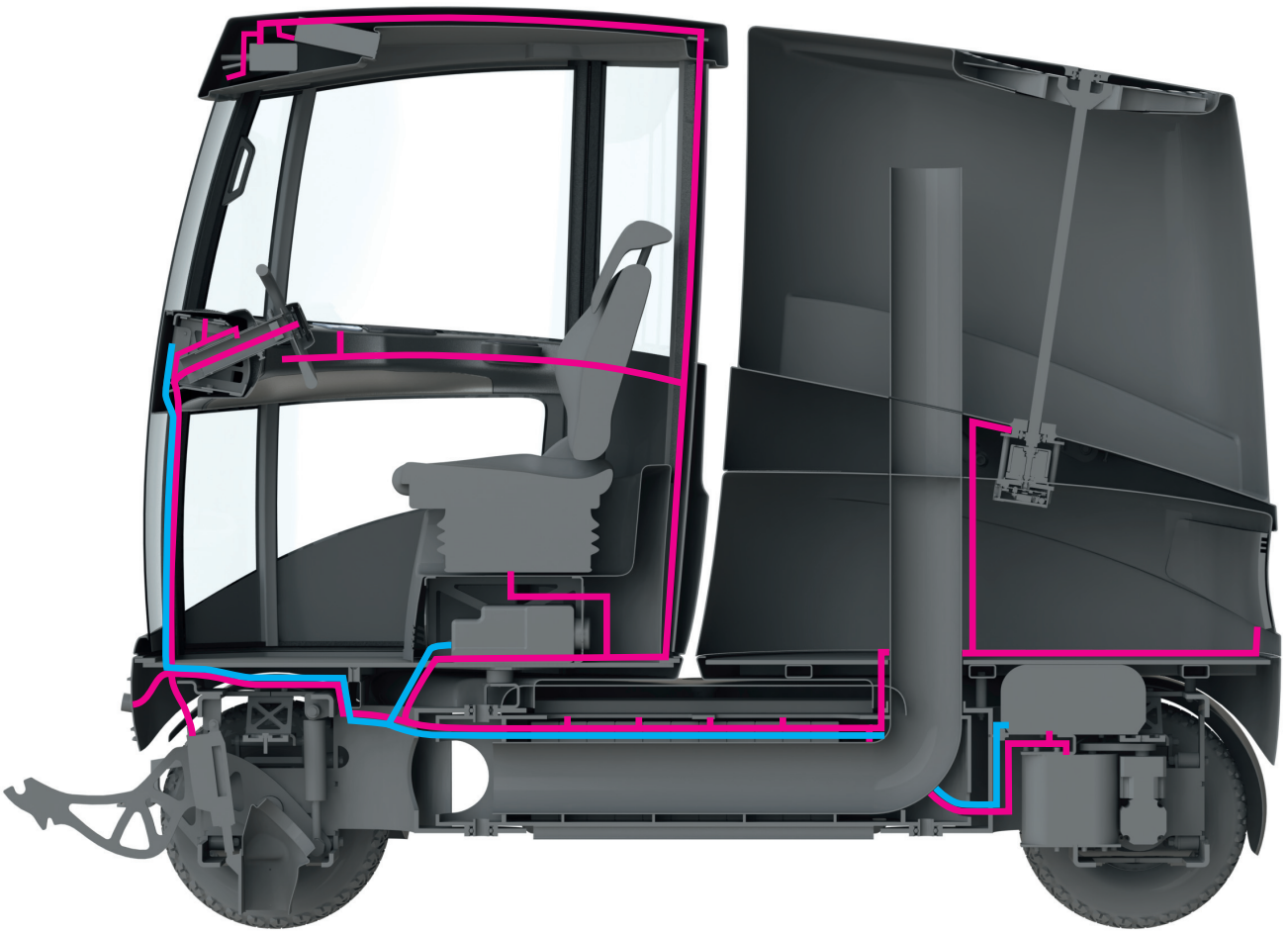
The daytime running lights comply with these requirements.

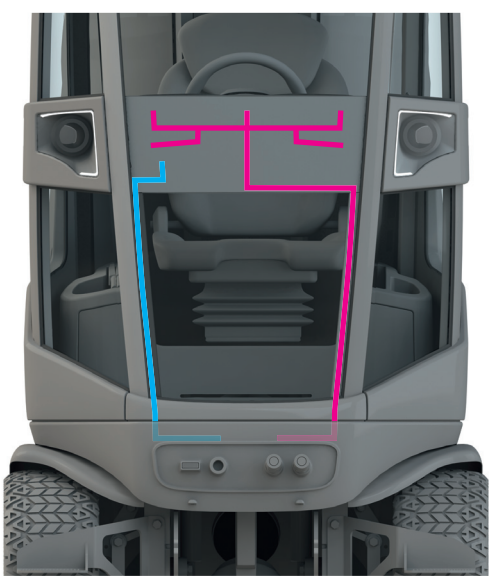
Tail lights
A tractor should be furnished with two tail lights, no higher than 150 cm from ground level and no lower than 35 cm. Should be visible 45 degrees inward, 80 degrees outward, and 15 degrees up and down ward. The distance between the lights should be at least 40 cm.

The tail lights comply with these requirements.


The tail lights have been produced to close the back end in a sweeping fashion. The selected tail light (pictured on top) has been drawn further in and been swept around the corner to reference the space between space between the band and shoulders on the doors.

# Wiring loom





Electric wiring loom
RadiJet heat exchanger hose

The RadiJet turbine supplies the vehicle with both power and heat. Heat is used to heat the cabin and batteries, the electricity is used to charge the batteries, and a few hydraulic hoses are used to drive the steering joints and lift arms. This diagram shows how the wiring of the machine is laid out.

# Production detailing

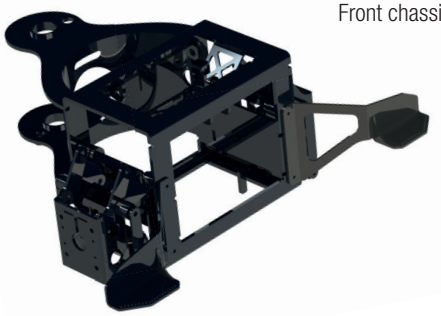
Production detailing is demonstrated on selected components. In plastics, this revolves around the part of the pilot band that is attached to the doors, and in sheet metal, the chassis is worked out. Assembly and maintenance is also touched upon. While many considerations throughout the thesis have dealt with mass production, the first series of vehicles is not expected to be feasible in large quantities. Thus an initial alpha series with a run of 20 units used as reference, and production methods are chosen to match.

The sheet metal approach used in this project resembles the one used in the VPM 3400, i.e. L.A.S.E.R. cut sheet metal with bends welded together – as opposed larger spot welded pressed sheet metal parts, as done in the automotive industry.

Chassis sheet metal parts, unfolded and folded.

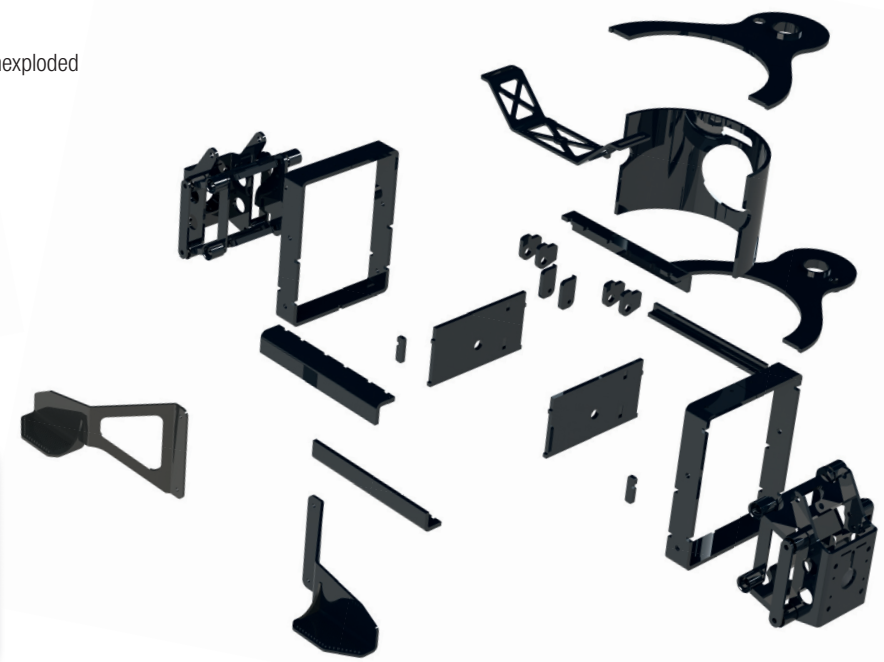
# Production detailing

A prevalent technique in sheet metal constructions, tabs function as alignment tools, largely negating the need for a welding fixture. These tabs also help to create an overview of how parts are joined and make sure (if done correctly) that parts are not mounted in reverse. This tab system is made prevalent throughout the chassis construction.



Front chassis unexploded

The chassis front is largely welded together. It consists of two frames joined by four cross braces. It is stabilised with plates, on which the lift arms are attached. A cross member provides a landing for the leaf spring.



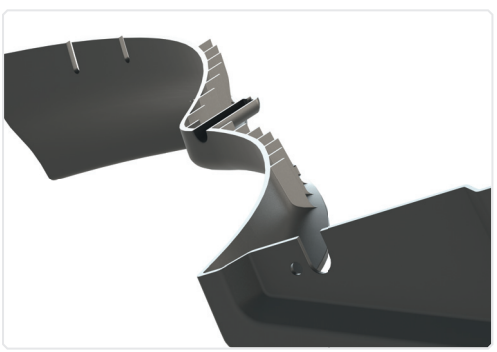
Front chassis exploded

The chosen steel is plate (EN 10051) – S235JRG2 as used by VPM-M in the current chassis, because of the combination of strength, price, and availability. As the chassis in particular is exposed to the elements, dirt and corrosive salts, it requires protection. After being welded together, the parts would be abrasive blasted to remove contaminants and to soften sharp edges, that would otherwise result in thin and fragile paint coat. Because of the corrosive concerns, the chassis should then be electroplated and finished with a powder coat. In this case, a dark colour is desirable to reduce visual clutter. RAL 9005 (Jet black) is chosen for the powder coat process.

# Production detailing

This plastic component of the pilot bridge interfaces with many components, and functions as a framework. The door card pictured here is the object of further detailing. It is secured to the door with three screws on top, one on the side, and two where the door latch protrudes. For technical drawings, see appendix O.

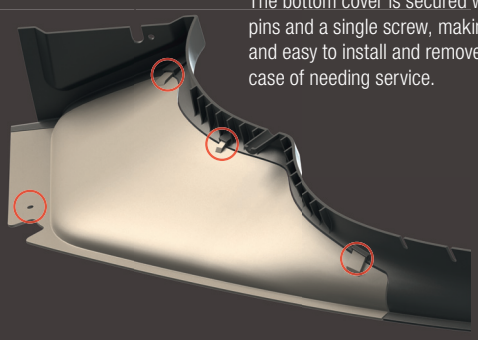
In designing plastic components, certain rules of thumb apply. Uniform material thickness, making rib thickness less than 70%, and height not more than 3x of material thickness. In addition to this, is the discipline of creating a component that can be extracted from the mould.



Cross section showing uniform nominal thickness and appropriately reduced thickness in the ribs to avoid shrinkage and warping during cooling.

The ribs are placed in the region of the hand rest, as it is expected that this is where stiffness is chiefly needed.

# Production detailing



The bottom cover is secured with three pins and a single screw, making it quick and easy to install and remove in the case of needing service.

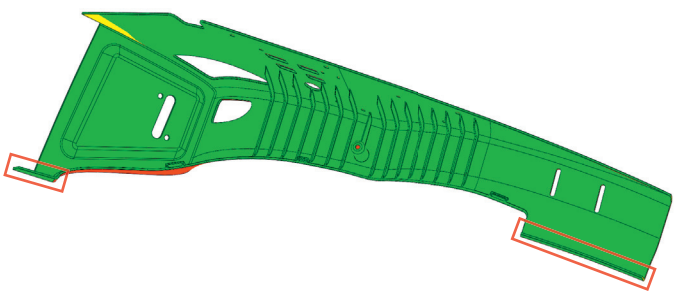
To secure other components such as the hand rests, snap-fit holes are provided in the base part allowing a quick, easy, and secure assembly.

The production technique employed here is vacuum casting, geared for production runs of 20-30 units. The mould is made from silicon, and as such, can allow for some undercut if made soft enough. The materials available here are many different grades with a full colour range of thermosetting PUR.

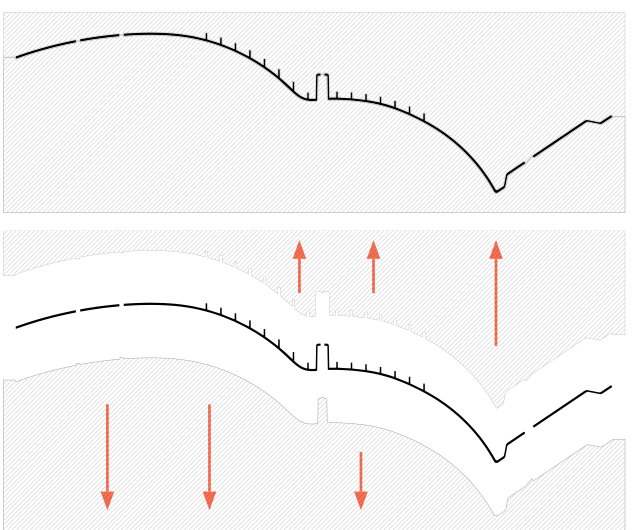
Shown here is a draft analysis with anything above 0.5 degrees in green. The yellow area still has a positive draft. The two highlighted ribbons have a slight undercut.

In the selected production technique, this is allowable, but if moving to a larger scale injection moulding technology, these issues need to be resolved.

While a draft of 0.5 degrees is sufficient for a smooth surface, a slightly larger draft is needed on the other side where surface texture is applied. This would be achieved by creating a tree part mould.

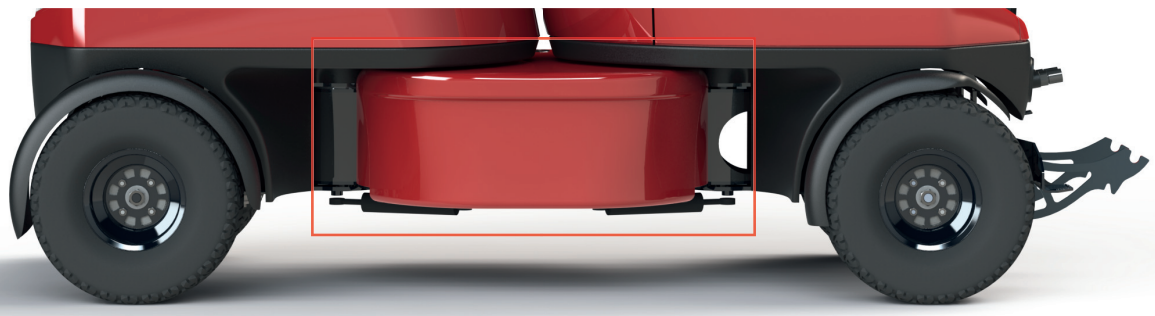


The colour chosen is a charcoal grey to reduce reflections in the glass. To create a more robust surface finish, the mould tech MT-11130 surface treatment is chosen.

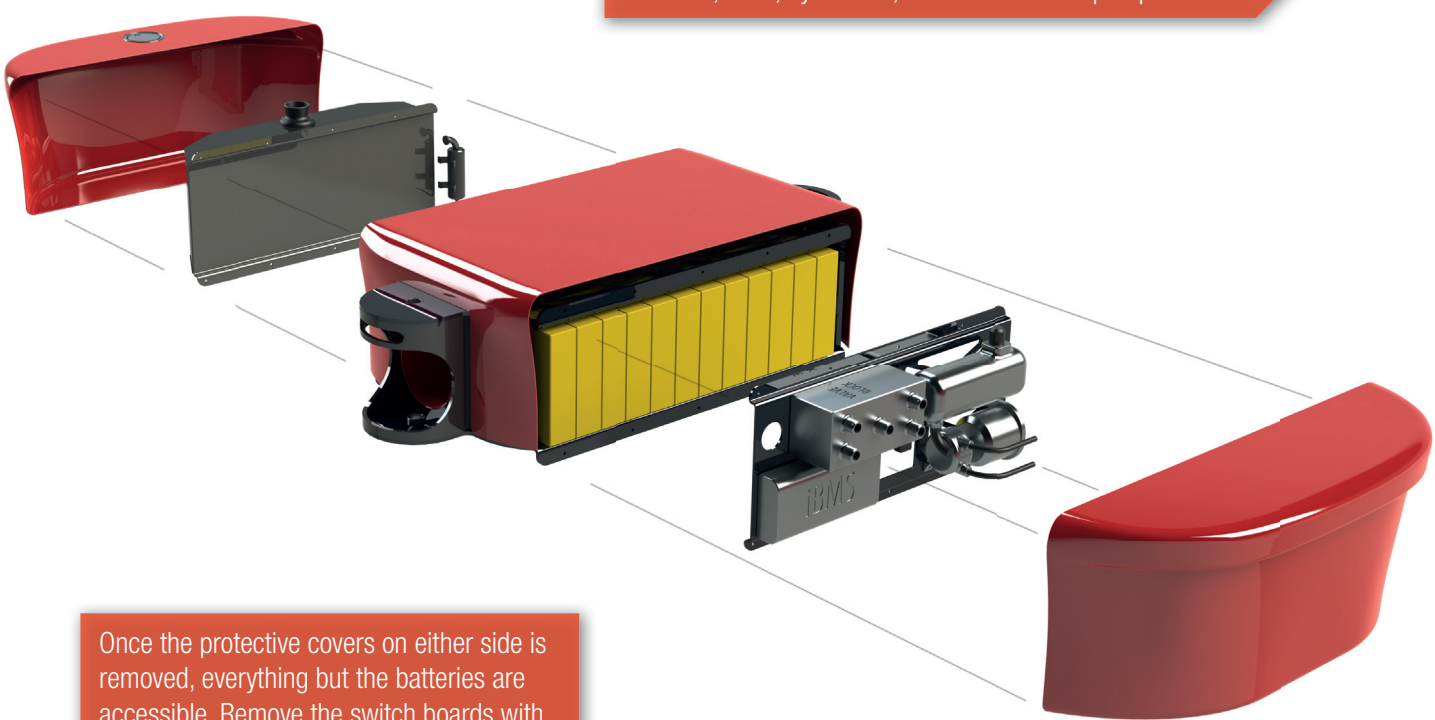


Here is a simple cross section, representing how the mould would separate during production.

# Maintenance



While servicing and maintenance is reduced in an electric vehicle (less moving parts, less fluids), it is not eliminated, and serviceability has to be considered. An example of the ease of accessibility, is the middle section of the platform that houses batteries, BMS, hydraulics, fuel tank and fuel pump.




Once the protective covers on either side is removed, everything but the batteries are accessible. Remove the switch boards with a few bolts and the batteries are directly accessible for service.

# Specs

Concluding the detailing chapter, basic specifications for the proposed machine is listed for use in making a comparison benchmarking against competitors in the launch section.


Kerb weight : 700 kg
Height: 2000 mm
Length: 2560 mm
Width: 1100 mm
Turning circle: 1100 mm
Wheelbase: 1940 mm
Platform height: 627 mm
Vacuum capacity: 750 litre
Water capacity: 300 litre
Vacuum pipe: 160 mm
Wheel size: 20 x 10”

Battery capacity: 7.2 kWh
Tank capacity: 22 litre
Run time: 8 hours

Jet turbine: 11 kW
Motors: Twin 8 kW
Gearing: 1:15
Moment: 1200 Nm

# LAUNCH

This chapter considers some aspects of launching the product. It discusses the market potential in terms of performance, price setting and branding.

# Benchmark

In order to clarify how the Flux stacks up against the competition, it is lined up against competitors mentioned in the research chapter, with an extra contestant of similar capabilities. Benchmarking is applied to vacuum capacity, dimensions of the machines, drivetrain parameters, and usage. Each property is scored from either very low to very high, or inverted. Which is best, is noted by max or min. The bars are arranged so that highest bars always equate best performance.

The horizontal line represents, VPM Flux's score to quickly evaluate its performance against the others. This comparison is performed on the basis of specification from manufacturers, some of which is approximate values. For specific numbers where applicable, see appendix P.

The volume capacity of the machines basically refer to the interval between return runs for disposal and refill. The ratio between these volumes and the bounding box is also mentioned, showing how efficient the design is.

Dimensions of the machines relates to the ability to manoeuvre around things, along with comfortable and stable driving. Interesting to note, is machine length and track compared to turning circle and wheelbase.

# Benchmark

Benchmarking the machines against each other is done to clarify and justify the price tag setting. As Flux is still a concept, it is obvious that not all parameters can be quantified and thus other aspect could influence the price setting. The exercise is meant to give an idea of immediate competition areas as means to evaluate if the product could provide a potential profit when estimating production price.

The general conclusion is that Flux in many ways effectively competes with many current offerings.

Drivetrain speaks about efficiency and flexibility in terms of delivered power. Fuel sources, shows ways of delivering the power. Emission and noise is guesstimated as comparable values does not exist.

Maintenance is day to day service and inspection. Tells about the complexity of the system. Indoor use is roofed and walled spaces. On this basis a target price for Flux is estimated

# Selling points

In the event of introducing the VPM Flux to the market, unique selling points quickly become relevant to outline why the customer should buy into VPM. These are linked to an estimated production price which in turn can be assessed by management. Marketing exercises should be conducted to evaluate market size potential, a topic which is only covered briefly in this thesis, by working with an existing customer base. Presented below are the USPs.

**User comfort**
- Completely flat floor without steering column
- Generous and articulated views combined with rear facing cameras
- Running board and large rear-hinged doors on each side for easy, ambidextrous access
- CANbus display unit on steering wheel, provides centralised drivetrain and tool overview/control
- Enclosing band with steering, feedback screens, and tool controls integrated into doors
- Adjustable steering wheel
- Convenient storage compartments, cup holder, hook for coat, and a mini-fridge
- Independent suspension on all wheels offer smooth ride
- Extended wheel base offers less back-and-forth-bouncy ride
- Soft close system on doors for easy and ear-pain-free door closing

**Manoeuvrability**
- Much increased wheel base for stability and ride comfort
- High speed and low speed manoeuvring due to ability to steer on front and back wheels separately
- “Crab” style manoeuvring
- Powertrain located between wheel axles for low centre of gravity

**Modularity**
- Base platform with complete drivetrain and hydraulic lift systems for massively increased module freedom
- Customisation for many different use scenarios and environments

**Drivetrain**
- Compact and efficient hybrid powertrain with RadiJet turbine, runs on diesel, petrol, E85, etc.
- Electric infrastructure combined with module-based system, provides options for future alternative powertrains such as hydrogen fuel cells
- Low noise levels
- Low service level required, compared to internal combustion powered machines

**Construction**
- Geared towards scaling in production quantities
- CNC bent aluminium profiles, dyed vacuum casted and thermoformed plastic panels for a light, tough, scratch resistant, and integrated construction
- Structurally integrated vacuum pipe
- Difficult to copy without a complete redesign

**Design**
- Emphasis on identity creation through prominent, integrated aesthetics
- Selective emphasis, highlighting user-relevant controls and functions, hiding user-irrelevant components, for a cleaner and less cluttered appearance

## PRICE ESTIMATION

Estimating production price for this many component entails a degree of uncertainty. For the purpose of this thesis, only a loose price estimation has been created. Tool costs is setup based on current tool prices. Creating a unit price involves; raw material, processing costs, labour, overhead, production setup, assembly and stock up. In a start-up production run of 20 machines it is estimated that a production price be around 220.000 DKK and at a list price of 440.000 DKK with 35% margin to the retailer will result in 65.000 DKK profit per machine. For calculations, see appendix Q.

# Brand

As already mentioned, one thing VPM is lacking, is a brand identity. Getting traction and creating a brand in a market requires time, effort, and a product of significant presence.

The name Flux derives from “fluctuations” in configurations, electric connotations, and perhaps the ability to create disruptions in the industry. The configurable platform is seen as a means to change the state of affairs in the business of tool carriers, being the first to implement hybrid technology.

The VPM logo, largely based upon a font, does not tells much about what VPM makes. On the machine the logo is accompanied by the model number and some leaves representing it ability to work all year.

VPM logo


Sticker on VPM 3400

The team has created some Flux logo suggestions, seeking to draw more attention and avoid technical description (such as the number of bhp multiplied by 100). This work is still in an early, unfinished state.

The team has also considered the strategy of making the machine itself a brand, or a sub-brand to VPM.


Because of the very different nature of Flux, creating a sub-brand could be a viable strategy if wishing to continue the VPM 3400. In such a situation, a new value set can be utilised without clashing with the current [Christensen, 1997].

# OUTRO

To conclude the thesis, the product is evaluated alongside a reflection upon the process and perspectives on the presented solution.

# Product evaluation

This section is devoted to discussing in what degree, and how the solutions satisfy the wishes and demands.
The background of the wishes and demands is based upon the approach of creating a radical improvement, a new generation tool carrier, instead of incremental improvement locked by legacy problems. As such current products were analysed to understand what competition a new product would be up against. This focused on extracting key features and well-functioning components to incorporate in the new concept. At the same time this screening, in an early project stage, delimits some of the components for development and rather uses a direct transfer or re-engineered approach.

## LEGACY IMPLEMENTATION

One of VPM-M's core values is their low noise cabin, compared to other competitors; while not directly measurable, this legacy is embraced through sealing and vibration reduction interfaces. In addition, replacing some of the primary noisemakers, a conventional diesel combustion engine and hydrostatic propulsion, with an energy efficient hybrid drivetrain not only make less noise, but also drastically reduces the vibrations that are part of experienced noise. The only noise-making component in the drivetrain is the jet turbine emanating a constant noise similar to that of an oil-fired boiler.

An important feature of any tool carrier in this size class, is its ability to manoeuvre around corners and as such must have a small turning circle. This in conjunction with the bounding box or track dimensions of the machine appears to be a general benchmarking characteristic to measure agility. As this thesis has progressed, it was found that additional characteristics are relevant. Utilising double articulated steering (DAS), Flux slightly improves turning circle while approximately staying within the overall dimensions. What is interesting is its performance with tools attached. Tool paths are changed with DAS, and allows for a much narrower turning circle when looking at machine extremities with the tools attached.

In the category of light re-engineering falls the implementation of suspension on all wheels alongside front tool interface. The suspension from VPM 3400 is modified to accommodate the integrated mouth piece and electric motors. Suspension on propulsion wheels is another challenge, as the driving motors cannot be directly attached to the wheel as done on the VPM 3400 because of the need for gearing. Because the wheels are translating and the motors are stationary, transferring power from the electric motors involve using constant velocity joints to allow for suspension movement. Regarding the front tool interface, the system is repositioned requiring a redesign of the lift arms, while keeping the action so that current tools can be attached. Repositioning the system also increases lift arm travel, allowing for picking up tools closer to the ground or lifting them higher. Because of DAS, loads from the lift arms are more directly transferred to the wheels, shortening the torque-arm that contributes to a bouncing machine.

Since these street sweeping is the most popular attachment, one of the major mistakes in the industry is neglecting to integrate a solid vacuum channel effectively into the machine. On the VPM 3400 integration is made to some extent, and improved heavily in the Flux as this was one of the key pointers from the beginning. Running a horizontal and vertical pipeline all the way except for the connection to the mouth piece, ensures minimal pressure loss due to less turbulence and drag. At the same time this provides a much cleaner look as it is hidden from view and is structurally integral.

In these regards, bringing legacy features to the new tool carrier from the VPM 3400, the thesis is deemed successful.

## WISHES AND DEMANDS

Another core value of VPM-M is operator comfort, which has already been mentioned in the above in term of suspension and noise. From field research the need for this has only been verified and thus demands are highly related. In Flux, comfort is processed in multiple areas, as means to heighten value of the product. A key aspect noticed when riding various tool carriers is a bobbing back and forth, due to narrow wheelbases. This manifested in an expressed demand for increasing the wheelbase, which does not mix with stability when turning in articulated steering. Partly because of this, the new double articulated steering type was developed, allowing for extending the wheelbase for increased comfort, while at the same time improving manoeuvring. Less bouncing and general stability is also achieved through heavy tools mounted closer to the wheels, and seating the driver between the axles rather than on top of.

During field studies other facets of user comfort was discovered – boarding and fields of view.
The fields of view concern navigating about, operating tools, watching out for people, benches, walls, etc.
Splitting the front A-pillars allows for direct visual contact with the tool extreme, enabling the operator to sit comfortable back in the seat. In conjunction with this, the pilot band enables the user to have visual contact with the lift arms that interface with the tools. Side mirrors were found to be cumbersome and unreliable, and are replaced with cameras in the same location to create the same “feel” and readout. These are complemented by a rear view camera on the back of the machine to reliably eliminate blind spots.

The steering wheel is the primary interface during operation, as this is what tracks the machine and tools. With the pilot band, car-like steering wheel adjustability is introduced, improving ergonomics by allowing the pilot to pull the wheel closer and tilt it into a natural position. In addition, the CANbus interface is centralised in the steering wheel, stationary even when the wheel is turned, keeping clear visual contact when showing readouts. It also presents six buttons for controlling the DAS and tool parameters such as speed. The pilot band makes for a vacant floor, enabling leg movement and different seating positions while operating for long periods.

In regards to boarding, investigation showed that a conventional steering column is in the way and this was the initiating reason for removing the column and introducing a pilot band. Entering the machine involves a step before and after.

As the floor is elevated relatively high above the ground, this puts quite a strain on the knee and creates a risky proposition if exiting onto slippery ground. This is remedied by fitting a running board. Due to the rear hinged doors and the placement of the wheels (DAS), it was challenging to implement in a satisfying manner, as space is scarce. As such a solution does require the user to enter in a specific manner. This solution might present issues as mud and dirt could gather around it, and possibly be in the way for having certain existing tools mounted on the machine. The last part of entering is closing the door, and this is generally an uncomfortable procedure because of ratio of door area and cabin volume, combined with poor rubber gasket alignment. In order to satisfy the demand for an improved closing experience, a soft close module is implemented to ensure successful, low-pressure door close every time. The hinges and door have been designed so that both of these can open, even when the machine is fully angled. Because of the hinge action, the door panel is flush with rest of the body, while pressurising the rubber gasket close to evenly just before being fully closed ensuring a tighter fit.

# Product evaluation

Due to the flat floor approach, space is freed up for storage compartments around the seating area. This allows for fitting a mini-fridge and makes room for tools, documents, and other peripherals.

From the design team's perspective it was important to challenge the aesthetics, in an effort to approach emotional design as means to create a product that could help define the VPM brand and remove focus from price competition to added value. A lot of inspiration has been taken from the automotive industry to create a vehicle with a personality and distinctive style. In this regard, the design team believes to have somewhat succeeded in creating a cohesive, integrated aesthetic expression where major features are derived from functions, such as the pilot bridge and DAS.

The platform that the design team arrived at, with its increased wheelbase, allows for a complete drivetrain package located no higher than the wheels. Centre of gravity is then very low and creates a solid foundation for building upon. In the configuration shown in the report, operation for an entire day is achieved by the hybrid solution. Depending on the fuel type used, the emissions are reduced or simply eliminated. Using hydrogen would render Flux a fully emission free machine and make indoor usage fully comparable to an all-electric solution. This hybrid drivetrain also features low weight as compared to both a diesel-hydrostatic system and especially an all-electric drivetrain where the batteries themselves would weigh in at 600 Kg. The latter is also possible on Flux with an expansion pack in the back box. What though is most interesting in terms of a low-slung platform is the ability to build configurations on top and having a large volume available within the bounding box.

The vacuum box is large compared to the existing model, and can certainly be optimised to achieve an even higher volume. This is the Holy Grail in street sweeping; effective cleaning time before unloading is required.

Four wheel drive in the current state is not possible. This is because of the nature of the chosen electric motors that need gearing in order to deliver enough torque. The motor and gear head assembly takes up more space than a hydrostatic motor, though it is much more efficient. Propulsion is only offered on the back wheels as a result, because the front compartment is filled with other features.

The bodywork is designed to be manufactured from plastics, rather than steel, over an aluminium skeleton. This creates a lighter, tougher exterior with regards to corrosion, dents and scratches. Attention to assembly order and ease has been given throughout the design process, though not at a level in where the machine is fully geared toward high volume manufacturing. Optimising components for fewer assembly steps and cheaper production is beyond the scope of the thesis. What has been given some consideration is an extract from the OECD code, testing the cabin cage to investigate structural integrity because of safety concerns. This is done to reveal obvious flaws before initiating prototyping and testing. The results revealed a sturdy construction that does not buckle under the forces required.

## VPM DEVELOPMENT BOARD MEETING

On January 12th 2012, the design team presented the Flux concept to the VPM-D board directors, in an effort get feedback and perspectives. The most commented feature during the discussion afterwards, was the DAS system. Especially one of the members was not convinced of the benefits and advised to clearly argue and illustrate why this should be implemented. The idea of a platform solution was acknowledged as a great potential to build different configurations at various price tags. Introducing the idea of a pilot band yielded positive response and resulted in questions about possibilities of implementing presented ideas in the VPM Electro. Using plastics for different components, including bodywork, was well received because of price, weight and corrosive properties. Overall the design direction was commented on as good looking and an up-market way to go, but also with the concern of it being too much of an improvement to be accepted by customers. The design team has endeavoured to take note of these concerns and notions, addressing them appropriately. For presentation slides, see appendix R.

# Reflection

This thesis has some interesting and far-reaching perspectives not fully expressed in the communication of the process report. The following text will elaborate on this further. As this thesis has also been a learning process, it seems natural to reflect upon the course and direction it has taken during the project period, and what could have been done differently.

## PROCESS

As a master thesis, the project seeks to demonstrate the project groups capabilities in terms of competencies accumulated throughout the education. One of the major corner stones in the industrial specialisation is the integrated design approach, and the inherent complexities of Flux provides ample opportunity for demonstrating such process handling. The accumulated toolbox of methodologies has been used as an means to an end, i.e. uncovering latent issues and understanding the user.

Managing a product consisting of this many components and independent design challenges, has not been done previously by the design team, resulting in unproven territory in terms of administration and overview. This implies figuring out how to structure and break down the product into subgroups for processing. Every day has given new inputs, new ideas, constantly moving towards framing the project.

The design team feels that the project handles the process of maturing a concept in to a detail level close to prototype stage at a satisfactory level. This very exercise shows the ability to translate ideas into something that can be produced, including knowledge and skill in working between the whole and the parts from which it is built, and all the steps in between.

Another aspect is in challenging habitual thinking in an industry to shift norms and standards. This is achieved by taking an outsider's point of view and getting one's hands dirty. The design team participated in relevant activities, such as the demos, trade fair, and bodystorming of the products. This kind of hands-on field study quickly illuminates issues, tendencies, pit-falls, etc.
This approach to research is of a qualitative character, focusing on observing and finding the unspoken, latent issues. Finding the root of a problem rather than trying to satisfy single, explicit wishes expressed by users, sales personnel, and management as a result hereof, is clearly the goal. Doing so leads to finding key fundamental features that can potentially outperform competitors in unconventional ways.

This project afforded the design team the experience of being an external design team entering and acting as design studio in a company unaccustomed to design thinking. This has been a most illuminating experience, as this is the first time that the design team has experienced the "real world" pressures and linear thinking that is present in this industry, and perhaps so in many. While the design team has had freedom to conduct the project according to the framework of an education, in the beginning there was much resistance to the habitual challenge-everything-attitude of the team. As the project progressed and the fruits of this approach matured and became more clear, the initial resistance has turned to support, praise, and constructive criticism.

As allured to, working from inside the company has been challenging in more than one way. The team was generously offered a workspace within the company for the duration of the thesis, which entailed a close relationship with contact on a daily basis. While this enables quick meetings to get fast answers as needed, the specific nature of VPM-M and VPM-D has been a source of difficulty. As the office was located in Aarhus and the production company in Stauning, the design team has only been to the production facilities a handful of times. Communicating with two separate firms located geographically far away has not been optimal. Though links between the companies exists, they have two different agendas. Thus keeping both parties up to speed never did function to the satisfaction of the team. VPM-M's involvement in the project after the research phase has been a minimum, which is unfortunate. The reason for this is partly the team's inability to create enthusiasm among employees in VPM-M, a company at the time struggling for survival. As such the team has leaned upon VPM-D for feedback. In retrospect it would have been preferable to have had a schedule, regular meetings for presentation of accomplished results, to get feedback and implement valuable information from Stauning.

# Reflection

Due to starting the project period as an internship, with a somewhat floating transition, equated multiple projects worked on simultaneously. Transitioning to the master thesis, and defining the scope hereof, was for a long period of time not communicated properly between the parties, leading to a late understanding in the company of how the project would unfold. While the design team early on had a discussion with the VPM-M chairman Henrik Sørensen, and the scope of the project was defined here from, this understanding did not filter through the organisation.

During the master thesis, the process of managing the development has in periods been a bit fuzzy, as allocation of resource and defining components of importance has mostly been on a spoken basis instead of fully utilising e.g. time management tools and QFD. The team did struggle somewhat with defining, planning and delimiting the project in a fashion that could be conveyed to external parties in the beginning. This led to much time spent on discussion topics already partly covered.

A lot of effort has been put into drawing in both 2D, 3D, and translating between, working with integrating form and function. In retrospect creating a systematic plan for individual component placement, early in the development process is very beneficial in term of incorporating the right features into the right components at the right time. In a project which has a lot of interfacing components, this is crucial to avoid long detailing hours, where conflicting details are discovered later rather than sooner. Even though the team believes to have created a cohesive solution where the components function in unison, some experiments and specifications could have resolved this even more efficiently and shortened the period of detailing.

Due to the geometrically complex shape of some of the component, a lot of work is required if radical changes need to be made. Utilising the master form modelling technique that allows for, in some degree, such subsequent changes. This approach needs a great deal of consistent modelling and knowledge about how each component interrelate in order to be successful. In this context it would be beneficial to specify the level of detail desired in each area seeking to allot time where best used. Working concurrently with a bill of materials could generate an overview of component levels in conjunction with a product architecture diagram, to review materials, volume and weight etc. If such a system was implemented, awareness of concurrent product architecture and progress might in an illustrated fashion have contributed to a better understanding of the product composition.

Working within a company setting has allowed usage of resources located in the firm's knowledge base. As a result, research has been conducted by the team and correlated with what already known to the company. This situation, relies on the validity of said knowledge together with the teams own experience through experimentation, field studies and research. Due to the desire to demonstrate transitioning from concept to detail, and time allotted for internship, a thorough investigation and usage of users in the design process could have had greater attention. This is reflected in little user feedback on setting up demands and wishes and proposed solutions to issues. Thus in the process of uncovering latent issues some perspectives might have gone past attention. A broader user contact, throughout the concept and detailing phases, could have been beneficiary, especially if conducted alone with no involvement from sales personnel as was the case in field studies.

In this thesis, with the scope defined in the introduction of the report, the design team has taken the tool carrier concept as an ideal solution to outdoor maintenance for granted. While one could argue that taking a bolder course and challenge the concept of outdoor maintenance would yield an entirely different product category, given the company's capabilities along with the realisation prospects, such solution would never be of consideration to VPM-M. Thus the approach of rethinking the fundamentals of the tool carrier's composition has been processed to comply with the project scope.

It could be argued, that with outdoor maintenance the ultimate solution would be an automated one. The tool carrier has arisen from a desire to reduce cleaning time and man power required at the same time. While such a solution is not currently feasible, gradual automation could be the way of the future as cameras and recognition software becomes smarter, cheaper, and easier to implement.

## PRODUCT

One of the design team's main aspects of concern regarding the product, is dubbed MAYA (most advanced yet acceptable) by Raymond Loewe. As the looks, and thus signal value, of the machine is so radically different to what is available in the industry, it might be difficult to introduce it to the market successfully if it is not ready. A question that might be posed is how can a small company like VPM manage to create such a machine without compromising other features or constructions. On the flip side, it could also invoke massive questioning to competitors inquiring why their machines can justify their price tags. Because of a very conservative industry, such considerations would require investigation as to how an audience would receive the product, and if incremental introduction is the way to go [Wikipedia, 2012].

As mentioned, the team has found great inspiration in automotive design, seeking to transfer a car-like feeling to the product. It is believed possible to transfer some signal values found in cars, into a tool carrier without getting a feel of unsuccessful car rather than a successful tool carrier. It is also believed that working with aspects which imbue an emotional character in products creates a competitive edge and can be brand building. This does though require that the product does not fail on a behavioural level.

## PLATFORM

The platform has arisen as a solution to some direct and many indirect requirements, and poses a new world of possibilities, in which the product (or the platform) could function. The ability to create configurations on top of the platform introduces application areas, which the product was not intentionally designed for. Thus allowing for expanding market possibilities with different configurations, rendering production more probable by an organisation having the right financing. The project is carried out on the basis of a customer clientele similar to the current, i.e. a small, low volume customer base. Because of the platform's capabilities such a market would not take full potential of its attributes. A self-propelling platform could be applied in various other areas. This could e.g. be on construction sites to transport building materials, a new generation auto rickshaw (people carrier), or airport infrastructure. Markets such as airports seem to have the greatest potential, as even a small airport such as Billund Airport, has 700 electric vehicles, tailored to a specific tasks. The use of hydrogen as a fuel source would enable indoor use as well, as the only emission would be steam.

## FEATURES

Further feature development on the Flux could centre on moving towards an intelligent, automated system. Utilising the camera/monitors solution for rear viewing, safety features could be implemented for less troublesome driving in crowded spaces, using detection software to notify the driver when objects and people get too close to the machine. It could also be expanded to functions such as tracking the tools.

Smarter tools is also a potential way to go, introducing for instance wireless tools, where there are no physical connections other than the mounting. Power could be transferred via induction (as is done in electric tooth brushes) and operating signal via optical signals or radio. This can be achieved as the machine is built on an electric infrastructure.

Another interesting feature could be adaptive suspension, since the loads on the back can conceivably vary with a ton. This can help solve rear tool alignment under heavy loads, as well as increased ride comfort. Such a system could be implemented by having a device that increases and decreases tension on the leaf spring in accordance with loads.

# APPENDICES

## APPENDIX LIST

Appendix A: Demo and open house

Appendix B: Elmia trade fair

Appendix C: Market analyses

Appendix D: Edwin Rahrs Vej interview (questions and transcript)

Appendix E: Focus group interviews (VPM-D)

Appendix F: Steering typologies

Appendix G: Aluminium 6082 data sheet

Appendix H: Relevant OECD code 4 (3.6.1, 3.6.2)

Appendix I: FEA front

Appendix J: LBD RadiJet calculations

Appendix K: CPM 90 twin data sheet

Appendix L: Front sweeper concept and technical drawings

Appendix M: Hella data sheet

Appendix N:  Relevant light regulations

Appendix O: Plastic technical drawings

Appendix P: Benchmarking spreadsheet

Appendix Q: Price calculations

Appendix R: VPM-D board meeting presentation

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http://www.vpmmaskiner.dk/public/IMG_2497-web.jpg
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